SAFETY EVALUATION OF CONVERGING CHEVRON PAVEMENT MARKINGS

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SAFETY EVALUATION OF CONVERGING CHEVRON PAVEMENT MARKINGS

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LIST OF ABBREVIATIONS

EB	East Bound
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
HOV	High-Occupant Vehicle
mph	Miles per Hour
NB	North Bound
NHTSA	National Highway Traffic Safety Administration
NOAA	National Oceanic and Atmospheric Administration
SB	South Bound
WB	West Bound

SUMMARY

Chevron pavement markings have seen rising interest in the United States as a means to reduce speeds at high-speed locations and improve safety performance. In Atlanta, there are two freeway-to-freeway ramps where chevron markings are being used. A previous study analyzed before-and-after speed data at these ramps and found only a modest reduction on overall vehicle speeds. However, a cursory crash analysis indicated that the ramps had crash reductions of over 60%, suggesting that safety benefits exist even though vehicle speeds are not significantly affected. This research aims to evaluate the safety performance of chevron markings on the two ramps in Atlanta, GA in order to quantify the potential impact of the treatment on safety and to understand the mechanism by which the treatment influences safety.

This thesis begins with a literature review covering topics in human factors in safety, past uses of different types of pavement markings, and methods in using crash databases and police reports in accident studies. Next, the thesis presents an in-depth before and after analysis of crash data from crash databases and police reports provided by the Georgia Department of Transportation. And finally, the thesis concludes with a summary of findings and a discussion of further research needs.

The results verified that there were 73% and 61% crash reductions in the two study ramps. Chevron markings appear to have benefitted all types of crashes and that they are possibly serving as a warning to drivers of potential upcoming hazards. Unavailability of a number of police reports and errors in crash databases were limitations to this study, and ultimately, new sites should be selected carefully and further studies need to be performed to better understand the treatment's benefits.

CHAPTER 1: INTRODUCTION

Finding innovative measures of speed control has always been of interest to the traffic engineering community. A non-traditional way to reduce excessive speeds is to alter the drivers' perceptions of the correct speed for a particular road so that drivers may assume a lower speed that is more appropriate [1]. One such measure is the converging chevron pavement markings. First proposed over a decade ago in Japan, chevron markings have seen rising interest in the United States. There are a number of locations in the U.S. where chevron markings have been utilized as a measure of speed control, including two sites in Atlanta, Georgia.

In 2010, the effectiveness of chevron markings in reducing vehicle speeds at two, two-lane freeway-to-freeway direction ramps in Atlanta, Georgia was evaluated. The study involved collecting speed data at the two ramps before and after chevron implementation, as well as at two control ramps where no chevron markings were implemented. One of the study sites is located at the north end of the I75-I85 Connector in Fulton County, Georgia. As Figure 1 shows, the Treatment Ramp where the chevron markings are installed is the I75 SB to I85 NB movement while the Control Ramp is the I85 SB to I75 NB movement. The second site is located at the interchange of I75 and I285 in Cobb County, Georgia. As Figure 2 shows, the Treatment Ramp at this site is the I285 EB to I75 NB movement while the Control Ramp is the I75 SB to I285 WB movement. The findings of this project indicated that the chevron markings had only a minimal impact on vehicle speeds, with drivers adjusting back to their previous speeds after they acclimate to the treatment. More specifically, the effects of the chevron markings on speed were most pronounced immediately after the implementation of the treatment. However, by the ninth month after implementation, the magnitude of the effect dropped to under 1 to 2 mph for the mean speed and most vehicle speed percentiles. While these findings do not necessarily imply that the chevron markings are not an effective safety treatment, it does imply that any safety benefits are not likely to result from a general decrease in speeds [2], [3].

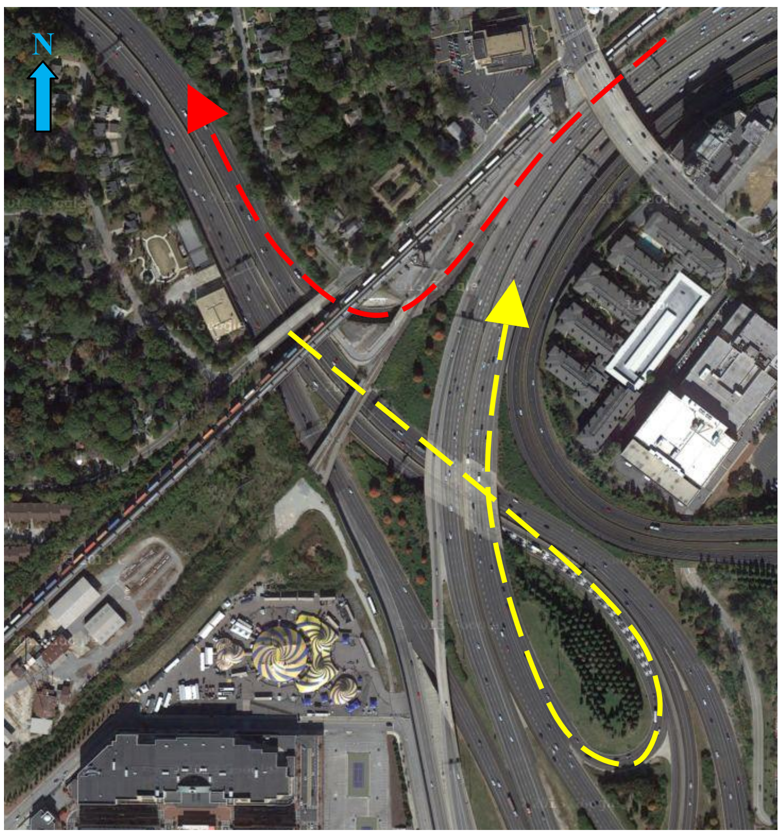


Figure 1: I75-I85 Interchange with Travel Direction for Treatment Ramp (Yellow Line) and Control Ramp (Red Line) [4]

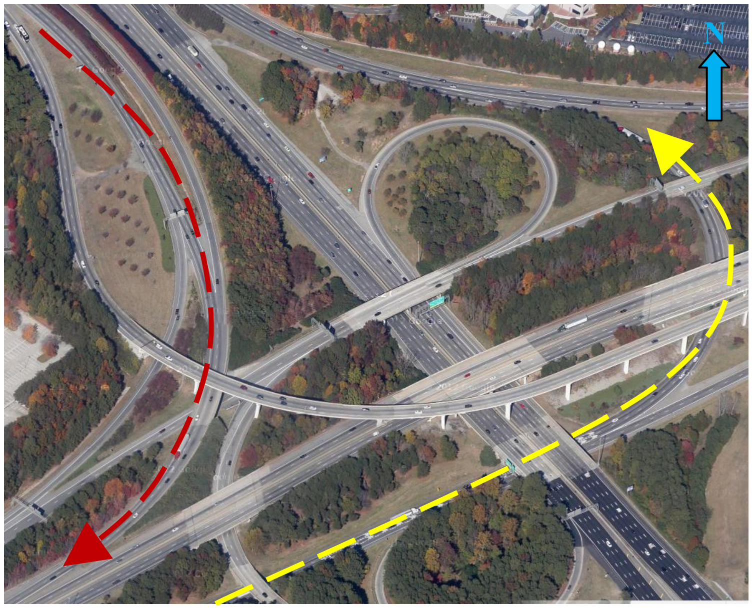


Figure 2: I75-I285 Interchange with Travel Direction for Treatment Ramp (Yellow Line) and Control Ramp (Red Line) [4]

After the speed study, a cursory crash analysis was performed for the two, two-lane freeway-to-freeway directional ramps in Atlanta, Georgia. This analysis showed that the two treatment ramps had 76% and 87% decreases in crashes in the 20 months after the markings were implemented. Meanwhile, the control ramps, where no chevron markings were installed, had only 15% and 20% decreases in crashes. This implied that the crash reduction on the treatment ramps significantly exceeds any expected background reduction, indicating that the chevron markings likely made a contribution to enhancing the safety of the facility. The question that this result poses, however, is that if the safety benefits are not due to a general decrease in speeds, then by what mechanism do they occur? For example, one possible explanation is that the chevron markings may be serving to alert drivers that are inattentive or unfamiliar with the area, thereby reducing the likelihood of a crash occurrence. Such a mechanism would impact a small number of drivers and have minimal impact on any aggregate speed measures.

This research aims to evaluate the safety performance of chevron markings on the two freeway-to-freeway ramps in Atlanta, Georgia, in order to quantify the potential significant safety benefits of the treatment and to develop an understanding of the crash types that are being addressed. This is accomplished by performing an in-depth before and after crash analysis using crash databases and police reports provided by the Georgia Department of Transportation (GDOT). This crash analysis first verifies the findings of the cursory crash analysis on the two treatment ramps and the two control ramps. Next, the attributes of the crashes are extracted from the crash databases and police reports, and analyzed in an effort to find underlying patterns in the crashes. Importantly, while this research has limitations, it is a step towards providing practitioners with a better understanding of the application of chevron markings. The findings of this research should help inform the selection of potential future treatment locations with potentially significant safety implications.

This thesis is organized in the following manner. Chapter 2 presents a basic overview of the concept of human factors in traffic safety and reviews several different types of measures of speed control. It then presents some examples of how crash databases and police reports can be used in accident studies. Chapter 3 describes the methodology used in the research, which focuses on determining the correct number of crashes in the before and after periods at both locations and on determining a set of crash attributes to be analyzed. Chapter 4 presents the analysis that is performed on the different crash attributes and discusses any patterns that are seen in the data. Finally, Chapter 5 discusses the implications of the Chapter 4 results, identifies limitations, and presents future research needs.

CHAPTER 2: LITERATURE REVIEW

This chapter describes the underlying concepts and factors pertinent to this research. This chapter first introduces the relationship between human behavior and traffic safety. It then discusses how pavement markings can be used to alter the driver's perception and information processing of the roadway system, discussing in detail several types of pavement markings. Following that, the chapter discusses two variables that have often been used to measure safety: vehicle speed and crash frequency. Lastly, it discusses the use of police reports in accident analysis.

2.1 Traffic Safety and Human Factors

In 2009, there were over 210 million licensed drivers in the United States [5]. According to the National Highway Traffic Safety Administration [6], in the same year there were over 5.5 million police-reported traffic crashes, in which 30,797 people died and 1,517,000 people were injured. With such high figures, it would therefore seem to be in everyone's interest to understand the mechanisms through which different crashes occur in an effort to develop countermeasures for them [7]. The efforts of many people in the research community to improve vehicles and the roadway system have helped decrease these figures in recent years. However, according to Olson and Dewar [8], not enough attention has been given to study the operator of the vehicles and the users of the system. A distinct characteristic of the transportation system today is that there is a great deal of control over the design of vehicles and of the roadway system, but not enough over the users [8].

The study of human factors is concerned with the interaction of people and devices of various kinds. In the case of the transportation system, these devices with which researchers are concerned are motor vehicles and their operating environment. This discipline aims to study human behaviors in the transportation system, focusing on their abilities and limitations. However, the issue of concern is that humans come in all shapes, sizes, attitudes, intellectual capability, physical health and psychological health. Compounding this with the fact that there are over 200 million licensed drivers in the U.S alone, it is not hard to imagine how difficult it is to address roadway safety issues as they relate to each individual driver [8].

2.2 Driver Perception and Information Processing

An important human factor that relates to this research project is perception and information processing. An estimate that frequently appears in literature is that 90% of essential driving-related information is acquired visually [9]. Vision is used to acquire basic information such as where the road is going, one's position on the road, the location and actions of other roadway users and the presence of potential hazards. It is the human sense that is used in most signals that originate from vehicles (e.g., brake lights, turn signals, etc.) as well as in the signs and signals placed by traffic engineers. To gain information from the surrounding environment, drivers also use other senses. For example, a pothole can be processed visually if the driver successfully sees it prior to driving over it, but in the case that the driver misses the pothole in his/her view, the driver will only know that the pothole is there when he/she drives over it. Driving over the pothole gives off a shock, or tactile stimulus, and sometimes an auditory stimulus as well. In both examples, the driver is able to gain information through many of his/her senses. The sensory information obtained is then processed in the brain in ways that help drivers to understand the stimulus and gain more information about it; this is what is called driver perception. In other words, perception is the end product of a complex process that begins with a physical stimulus [9].

Since the sensory information that is available to drivers is important in how they perceive the roadway environment, it is only logical that traffic engineers would attempt to change the sensory information available to drivers in order to convey some type of message to them (e.g., an upcoming hazard). In relation to vehicle speed, changing the sensory information available to drivers has become a measure to control it. The following section discusses further in detail some examples of how changing the sensory information available to drivers is being used as a measure of speed control.

2.3 Passive Measures of Speed Control

Passive measures of speed control are those that attempt to change the fundamental sensory information available to drivers to influence their speed behavior. By designing what sensory information is available to drivers on the road, the driver's perception of speed can be altered, persuading them to slow down. This type of speed control has several advantages over traditional speeding countermeasures such as speed bumps. It has the potential to reduce vehicle speeds without drivers being aware of its purpose, and its benefits are expected to be long term as they are less obtrusive measures less likely to frustrate drivers [1].

Pavement markings are prime examples of passive measures of speed control because of their visual, vibratory, and auditory characteristics that can be used to control the sensory information available to drivers on the road. An example of how pavement markings can be used visually to influence vehicle speeds is pavement markings in the form of centerlines and edgelines. Centerlines and edgelines can be painted on the roadway in such a way that narrows the effective lane width though the physical lane width is not changed [1]. An example of how the visual and vibratory characteristics of pavement markings are used for speed control is in the form of transverse pavement markings. These markings can be painted on the roadway and spaced at decreasing distances apart. Vehicles traveling through these markings at a constant speed will not only see in their peripheral vision that the markings are passing by at an increasing rate, but they will also feel the markings as they run over them at an increasing rate. These effects are designed to affect the driver's perception of speed, which consequently will suggest to the driver that he/she needs to slow down [10]. The following section will discuss the different types of pavement markings that have been used in the past as a measure of speed control.

2.4 Performance of General Pavement Markings

There has been considerable research done on the safety performance of various pavement markings. These efforts have demonstrated, in numerous instances, the potential of pavement markings as a treatment for crash reduction. The following sections discuss the findings of the research done on the safety performance of various pavement markings, other than converging chevron markings. The use of chevron markings is discussed separately in section 2.5.

2.4.1 Transverse Bars

A study performed by Godley et al. [10] investigated the psychological mechanisms of transverse bars responsible for speed reductions using a driving simulator. Twenty-four experienced drivers were obtained for the study. The simulated driving scenario involved driving towards intersections with transverse pavement markings at both reducing and constant spacing. Three different scenarios of transverse bars were used in the simulation: (1) full-length transverse bars extending from the edgeline to the centerline, (2) peripheral transverse bars extending 0.6 meters from the edgeline towards the centerline and, (3) no transverse bars.

The study found that all types of transverse bars reduced travel speeds during the treatment areas only, or in the portion of the roadway that has the actual transverse bars. Full-length transverse bars reduced speeds more than peripheral transverse bars only in the beginning portion of the treatment area. Interestingly, however, no speed differences were found between the two transverse bar spacing schemes, suggesting that the illusion of traveling faster did not influence the vehicle speeds. These findings suggest that the transverse bars reduce speeds through alerting drivers when they initially reach the treatment area and also through the peripheral perception experienced throughout the treatment [10].

2.4.2 Longitudinal Markings

Longitudinal pavement markings are an example of a marking type that is generally used to narrow the effective lane width of the roadway by use of a gradual inward taper of the existing edgeline marking. Retting et al. [11] performed a before-and-after study to evaluate the influence of longitudinal markings on traffic speeds at three urban freeway exit ramps in Virginia and one urban freeway exit ramp in New York. Traffic speeds were measured approximately 6 weeks before and 2 weeks after installation of the pavement markings. The longitudinal markings used in one of their experimental ramps in New York can be seen on Figure 3 and Figure 4.

The study found mixed results in the effectiveness of the longitudinal markings. Passenger vehicle and large truck speeds were reduced significantly at the New York ramp and at two of the three Virginia ramps. The proportion of passenger vehicles that exceeded the posted speed limit by more than 10 mph was also reduced in these three sites by at least 6% - the highest reduction of 17% was found in the New York ramp. Similarly, the proportion of large trucks that exceeded the posted speed limit by more than 5 mph was also reduced in these three sites by at least 17%. These findings, however, were not found in the third ramp in Virginia.

Figure 3: Longitudinal Marking at Experimental Ramp in New York – Before [11]

Figure 4: Longitudinal Marking at Experimental Ramp in New York – After [11]

Lum [12] also studied the influence of longitudinal markings used to reduce the perceived lane with of roadways. In contrast to the previous study by Retting et al., however, the study by Lum was performed in residential areas. Solid white edgelines were added to the road and raised pavement markers were installed at the broken centerline to create the impression of a narrower street. The study showed that these longitudinal pavement markings combined with raised pavement markers have no effect on the mean speeds or the speed distribution of the drivers [12].

Although there have been mixed results as to the effectiveness of longitudinal markings on reducing vehicle speeds, these studies ultimately exemplify the visual-illusionary potential of pavement markings.

2.4.3 Transverse/In-Lane Rumble Strips

Harder et al. studied the effects of in-lane rumble strips on the stopping behavior of attentive drivers [13] and sleep-deprived drivers [14]. The results of these studies show that the presence of rumble strips has no effect on the point at which the driver begins to slow down (i.e. takes his/her foot off the gas pedal) or on the distance away from the intersection at which he or she actually stops. The presence of rumble strips only affects the point at which they begin to apply their brakes. The results show that attentive drivers used their brakes earlier, and more often, in the slowdown process at intersections with rumble strips [13], [14]. Interestingly, however, no apparent effects of sleep-deprivation were found to influence the braking patterns of the drivers [14].

Thompson et al. [15] also studied the effects of transverse rumble strips as a warning device for drivers approaching rural stop-controlled intersections. Overall, the study found that transverse rumble strips produced statistically significant reductions in approach speeds. However, these speed change reductions were only equal to or less than 1 mph, which suggests that the results should be interpreted with caution.

2.4.4 Centerline Rumble Strips

Rural two-lane roads generally lack physical measures to separate opposing traffic flows, such as wide medians or barriers. Consequently, a major issue on these roads involves vehicles crossing the centerline and either sideswiping or striking the front ends of opposing vehicles. A study by Persaud et al. [16] evaluated the potential of centerline rumble strips as a countermeasure for such crashes. The centerline rumble strips are placed to alert distracted, fatigued, or speeding motorists whose vehicles are about to the cross the centerlines and into opposing traffic lanes. The results of the study indicated a 14% reduction for all types of injury crashes with a 95% confidence interval, specifically a 25% reduction for head-on and opposite-direction sideswipe injury crashes with the same confidence level.

2.4.5 Summary of General Pavement Markings

In summary, there are many different types of pavement markings that have been used as a measure of speed control and the studies performed to evaluate their effectiveness have found some mixed results. However, this does not necessarily show that these pavement markings are ineffective as a measure of speed control and essentially of safety. In fact, similar to the first study done on the chevron markings in Atlanta, this may suggest that using speed as a surrogate of safety may not be an effective way to evaluate the effectiveness of these treatments. As discussed in Chapter 1, in this study, crash reduction was actually observed though speed reduction was minimal [2], [3]. This suggests that more studies need to be performed on these pavement markings to arrive at a more concrete conclusion. The following section will now discuss the past use of chevron pavement markings and their performance.

2.5 Performance of Chevron Pavement Markings

As discussed in Chapter 1, converging chevron pavement markings used in Atlanta showed a minimal decrease in vehicle speeds [2], [3]. This section discusses in detail the use of chevron pavement markings in other locations in the United States and in the world.

2.5.1 Osaka, Japan

A converging chevron pattern to create the illusion of traveling faster as well as the impression of narrower lanes was first used in Osaka, Japan in the early 1990s [17]. There were six roadway segments where chevron markings were installed in Osaka. Although direct results from these locations are not available, research reviews cited that before and after studies in Japan indicated an effective reduction in crash frequencies when using chevron and comb pavement markings [1]. Drakopoulos and Vergou [17], however, stated that although an overall reduction in crash frequency was seen, there were a number of limitations. First, the number of crashes was very small in the first four locations, especially in the after period. Second, the last two locations had adequate sample sizes and showed consistency between the two before and after years, but the overall reduction of crashes was not statistically significant. Therefore, the research reviews suggest that more years of data needed to be analyzed to arrive at definitive conclusions. Figure 5 and Figure 6 show a layout of the pavement patterns used in Japan.

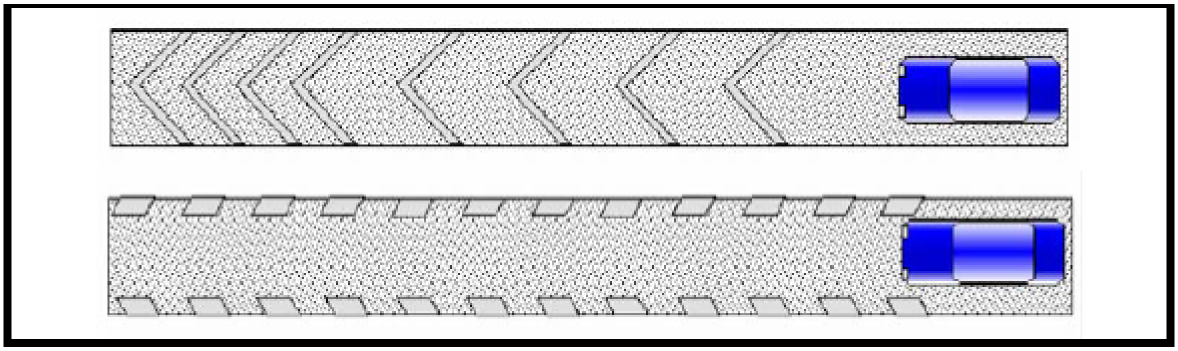


Figure 5: Chevron and Comb Patterns Used in Japan [1]

Figure 6: Chevron Pattern Applied on the Yodogawa River Bridge, Japan [1]

2.5.2 Milwaukee County, Wisconsin

Drakopoulos and Vergou [17] reported on the effectiveness of the chevron markings in reducing vehicle speeds at the Mitchell Interchange South-to-West ramp in Milwaukee County, Wisconsin. Two ramps were chosen for comparison in this study: a treatment ramp where chevron markings were installed, and a control ramp that had similar geometric and traffic characteristics. At the treatment ramp, detectors were placed 1,960 feet upstream of the beginning of the chevron markings and also 40 feet downstream from the end of the chevron markings. At the control ramp, two detectors were placed side-by-side 200 feet downstream from the ramp point of curvature. Speed data were collected 4 months before and after the installation of the chevron markings.

The study found that the chevron markings in the treatment ramp contributed to a statistically significant average speed reduction of approximately 12.5 mph between the before and after installation periods. The chevron markings were expected to affect speeds during the least congested parts of the day, when higher levels of congestion did not influence speeds. However, speeds were found to be lower during each hour of the day, both during weekdays and weekends. In addition, both the treatment and control ramps had lower numbers of crashes in the after period despite higher traffic volumes, though this finding was not statistically significant.

2.5.3 El Paso, Texas

Voigt and Kuchangi [18] reported on the effectiveness of chevron markings in reducing speed at the freeway-to-freeway connector of US-54 westbound to I-10 westbound in El Paso, Texas. Four data collection stations were utilized at the midpoint of the curve, at the start of the curve, upstream of the curve, and far upstream of the curve. Three discrete periods of data collection were implemented: before, early-after (1-3 months after), and late-after (4-6 months after). The duration of each data collection period was typically three to five days.

Comparison of mean speeds for all vehicle classes between the before and early-after periods indicated a slight decrease of speeds at the start and middle of the curve, with heavy trucks being the most affected by the chevron markings. The magnitude of the decrease, however, was about 0.14 to 0.45 mph. Although this magnitude is small, the effect of the chevron markings in decreasing the speeds was found to be statistically significant at a 95% confidence level.

Similarly, comparison of mean speeds for all vehicle classes between the before and late-after periods indicated a significant reduction in speeds at the upstream and start of the curve, with heavy trucks being the most affected once again. Moreover, the magnitude of reduction in mean speeds was much greater than the reduction in speeds between the before and early-after periods. This indicates that the effectiveness of the chevron markings did not degrade over time.

The study also found in the before and late-after comparison that mean speeds at the middle of the curve showed a significant increase for all vehicle classes. This observed increase could be due to motorists slowing more before the curve, but then judging the upcoming curve and accelerating through. In this situation, the chevron markings appear to serve as only an indication to the motorists that there is an upcoming hazard they need to be attentive to, but not as something that they necessarily had to slow down for.

Over 60 percent of all vehicles in all study periods were also found to be driving at least 15 mph over the posted speed limit at the start of the curve: 72 percent in the before period, 69 percent in the early-after period, and 67 percent in the late-after period. An increase in the percentage of these vehicles was seen in the mid-section of the curve, indicating that vehicles may have become more familiar with the chevron markings by the late-after period. These findings once more suggest that the chevron markings are only serving as a warning to the motorists of the upcoming sharp curve.

2.6 Measures of Road Safety

The studies presented in previous sections utilized both speed and crash frequency as measures of safety. Between these two, the use of crash data is more traditional [19]. However, the use of crash data has several limitations with respect to availability and accuracy. This section discusses the issues associated with crash data as well as alternative measures of road safety that have been used in the past in place of crash data.

There are limitations to the use of crash data due to the following reasons. First, occasionally there are a small number of crashes not only in the after period but also in the before period which leads to insignificant and inconclusive results; this was apparent in the first chevron markings study in Osaka. Second, crash data generally lack the details that are needed to be able to understand the mechanism of the different accidents, especially those pertaining to the driver's accident avoidance behavior. In addition, the use of crash data for safety analysis is a reactive approach, meaning that a significant number of crashes would need to occur before a study can be performed [19]. Consequently, surrogate measures of safety have been proposed and used in place of crash data because it potentially allows for an earlier safety assessment.

Speed is a surrogate measure of road safety that is widely used. In fact, most of the studies discussed in sections 2.4 and 2.5 have all used speed as their measure of safety. These studies directly translate any changes in vehicle speed to a change in road safety. However, a change in speed is not directly translatable to a change in crash frequency and a change in road safety [19]. A prime example of this can be seen in the current study on the safety performance of chevron pavement markings. The analysis of the before-treatment and after-treatment speed data indicated that the chevron pavement markings had only a modest impact on the vehicle speeds [2], [3]. However, a preliminary crash analysis actually shows that the crash frequency in the two treatment ramps decreased by at least 60%. These results suggest that there is a safety factor that is affected by the chevron treatment but the effect was not captured by a surrogate measure (i.e. speed).

Various factors that affect safety can be divided into two categories as shown in Figure 7. One category consists of the factors whose influence can be captured with a surrogate measure of safety. For example, the influence of insufficient sight distance at an intersection can be measured using measures such as post encroachment time and time to conflict [20]. The other category consists of the factors whose influence cannot be captured by a surrogate measure, such as driver expectancy, driver inattentiveness, or other human factors. In cases like the second category, crash data would need to be used to perform a safety analysis though they come with limitations of their own as discussed previously.

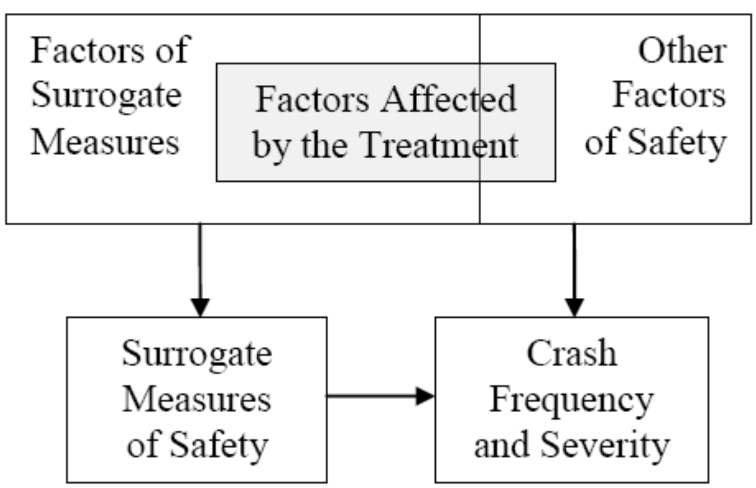


Figure 7: Relationship between Surrogate Measures and Safety [19]

2.7 The Use of Police Reports in Accident Analysis

As discussed in section 2.6, there are several limitations to using crash data, including the possibility of having a small sample size and the fact that the use of crash data is a reactive approach. Indeed there is also the possible lack of details in the crash data that are needed to understand the mechanism of different accidents. However, there is a more important issue in using crash data that needs to be addressed and that is the issue with human interpretation of police reports.

Today, accident police reports are still hand-written by police officers that come to the accident scene. A generally agreed upon computerized method to generate and store police reports has not been created. A computerized method that enables police reports to be stored in a type of database would ease any analysis that needs to be performed on them. The concern with this is that due to the differences between police reports, the accident investigator, in attempting to piece together the bits and pieces of evidence, is susceptible to many psychological processes that may lead to errors in judgment [7]. To compensate for this, some researchers have created their own database of police reports in order that they may analyze them in a more time-efficient manner and in a way that minimizes judgment errors. However, a fully computerized procedure of analyzing police reports is also undesirable because the causal scene of each accident may be difficult to capture using algorithmic methods. Hence, there is a balance to be struck between the judgment and experience of a researcher as a source of insight and the additional findings that may be possible through computer [21]. The remaining text in this section outlines three items that should be considered to successfully utilize police reports in performing accident analyses.

Level of Detail

An issue with using police reports in accident analysis is that there are most likely varying levels of detail in each report due to different police officers that write them. Hence, it is important to keep track of these variations. For example, each police report can be given a grade of A or B. A grade of A is assigned to those that contain high level of detail allowing a full interpretation of events while a grade of B is assigned to those where the overall level of information is lower [21].

Interpretation

Police reports should also be interpreted and summarized by more than one person. At least two persons, who are both experienced researchers and drivers, should read and interpret each accident case and any disagreements in interpretation between them should be resolved with the help of a third member of the team [21]. Moreover, it would also be beneficial if the interpretation procedure generated a standardized format of all the needed information from the police reports, including factual details, figures, prose accounts, graphics, and explanatory factors. This would eliminate the different levels of details that exist between police reports and place them all in a leveled playing field [22–25] .

Database

Each accident case complete with their standardized information could then be entered into computer database software. Once all the cases are entered, the process of hypothesis creation and testing can begin, using the search routines in the database to identify contrasting subgroups of cases. Each subgroup of cases can then be analyzed in detail to filter out possible common accident mechanisms. Regrouping or further dividing the sets of cases can also be performed, reiterating the process until stable and consistent conclusions are reached [26].

The ultimate aim of entering all the data into the database should be to build a library of standardized and individually analyzed cases. Since each accident has been analyzed individually, the database is only used to find groups and recurring patterns and not as a container of raw data awaiting analysis [25]. It is necessary to stress that using the database does not remove the need for human inspection, evaluation and interpretation of the data. In fact, it increases the need for them [21–26].

CHAPTER 3: METHODOLOGY

The analyses performed in this project are based on two primary sources: crash databases and police reports. In the same way, the methodology is divided into the same two divisions. The following text presents the steps that were taken with these two sources.

3.1 Crash Database

The purpose of using the crash databases was to extract the crashes that occurred in the I75-I85 interchange ramps and I75-I285 interchange ramps in order to analyze their attributes to find any underlying patterns that could be attributable to the chevron markings treatment. Several steps went into preparing the data before the analysis of the crash attributes could be performed. A byproduct of these steps is the verification of the cursory crash analysis performed in the earlier study [2], [3].

3.1.1 Definitions of Essential Variables

Before any crash records for specific interchanges could be obtained from the crash databases, there was a need to determine how location attributes were stored in the databases, specifically those pertaining to interchanges and interchange ramps. The Ramp and Location tables in the databases store several different location variables that together would help in identifying crash locations. These variables are: County ID, Route ID, Interchange ID, Interchange Add-ID, Quadrant ID, Ramp ID, Ramp Section ID and Accumulated Mile Log. Definitions of all the variables in the crash databases were provided by GOT and are available. However, some definitions are very limited and do not adequately explain the variables. After some exploration of the crash databases and double-checking with police reports, a more concrete set of definitions for these variables have been generated, as will be discussed in the following.

County ID

County ID is a variable from the Location Table, also named LOC_COUNTY_ IDENTIFER. It is a three-digit variable that refers to the county code where the crash occurred. Table 1 below shows the GDOT county codes for the 20-county Atlanta metropolitan area.

Table 1: GDOT County Codes for 20-County Atlanta Metropolitan Area

County ID	County Name	County ID	County Name
13	Barrow	117	Forsyth
15	Bartow	121	Fulton
45	Carroll	135	Gwinnett
57	Cherokee	139	Hall
63	Clayton	151	Henry
67	Cobb	217	Newton
77	Coweta	223	Paulding
89	DeKalb	247	Rockdale
97	Douglas	255	Spalding
113	Fayette	297	Walton

Route ID

Route ID is a variable from the Location Table, also named LOC_ROUTE_ IDENTIFIER. It is a four-digit variable that refers to the state route number of the facility. Each interstate in Georgia has its own state route number. The two interchanges of interest are I75-I85 and I75-I285. Thus, there are 3 interstates that need to be noted for this project: I75, I85, and I285. Table 2 shows the Route ID numbers for these 3 interstates.

Table 2: GDOT Route ID Code for I-75, I-85, and I-285

Route ID	Interstate Name
0401	I-75
0403	I-85
0407	I-285

<u>Interchange ID</u>

Interchange ID is a variable from the Ramp Table, also named RMP_ INTERCHANGE_IDENTIFIER. It is a three-digit number that represents the interchange number and only crash records that occur on or close to an interchange have this variable. An interchange number is essentially the exit number one sees on the Interstate that represents the upcoming interchange.

According to the FHWA, states typically use one of two systems for numbering their Interstate interchange exit numbers: (1) the consecutive numbering system and (2) the milepost numbering system. The FHWA definitions for these two systems are the following:

- *The Consecutive numbering system – Starting at the most westerly or southerly point of each Interstate route, interchanges are numbered consecutively. Thus, the first interchange becomes Interchange #1. Each succeeding interchange is numbered consecutively as #2, 3, 4, etc.* [27]
- *The Milepost numbering system – All Interstate routes are mileposted beginning at the most westerly or southerly point. The beginning point is milepost '0'. If the first interchange on the route is located between milepost 4.0 and 5.0, it is numbered as Interchange #4. The next interchange, if located at milepost 8.7, would be numbered as Interchange #8, etc.* [27]

In Georgia, the consecutive numbering system was in use prior to 2000. In January of 2000, however, GDOT began changing the numbers on its 5,670 exit signs along its interstates to the Milepost numbering system; the change was finished by June of that year [28]. Both number systems may still be in use within the crash databases.

Interchange Add-ID

Interchange Add-ID is a variable from the Ramp Table, also named RMP_ INTERCHANGE_ADDIDENTIFIER. It is a one-character variable that represents the continuation of the ramp interchange number. Although its exact definition is not available, it appears to be a variable that holds the letter occasionally following an interstate exit number (i.e., the letter A in exit 12A).

Quadrant ID & Ramp ID

Quadrant ID is a variable from the Ramp Table, originally named RMP_QUADRANT_ IDENTIFIER. It is a one-digit number that represents the quadrant in which the ramp is located. An exact definition of how the quadrant system references the interchange layout was not found. However, a small police report study was performed on a simple diamond interchange, specifically the interchange of I-285 and La Vista Road in DeKalb, GA, in order to determine how the quadrant system is formatted. The results can be seen on Figure 8, where Quadrant I is the northwestern quadrant and the rest follows in a counter-clockwise manner. This, however, is not conclusive evidence about the entire dataset and the quadrant system of an interchange should always be determined in a case-by-case basis.

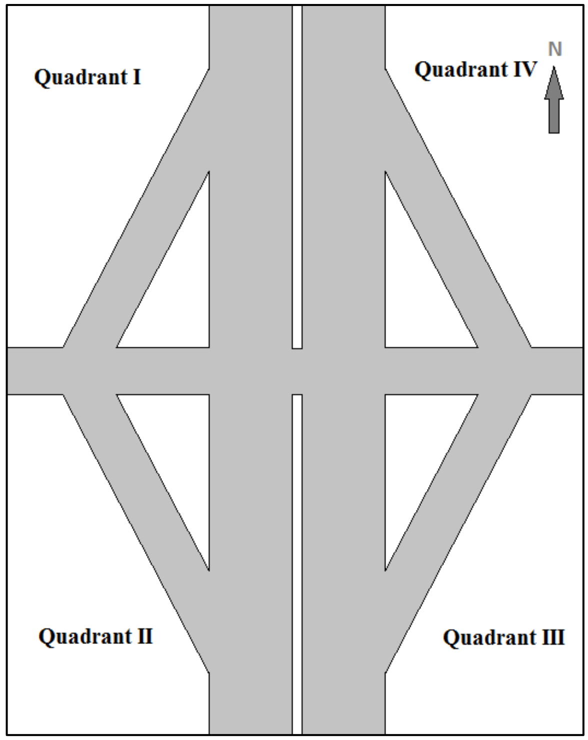


Figure 8: Ramp Quadrant System in a Diamond Interchange (Diagram by Prabha Pratyaksa)

Ramp ID is a variable from the Ramp Table, originally named RMP_RAMP_ IDENTIFER. It is a one-digit number, but its exact definition is unknown. From exploring the crash databases, the variable appears to differentiate ramps that are located within the same quadrant. However, an exact definition should be obtained from GDOT in future studies.

Ramp Section ID

Ramp Section ID is a variable from the Ramp Table as well, originally named RMP_ RAMPSECTION_IDENTIFIER. A ramp on an interchange is divided into three sections and this one-digit variable, ranging from 1 to 3, represents the ramp section where the crash occurred. The different ramp sections are generally defined as shown on Figure 9.

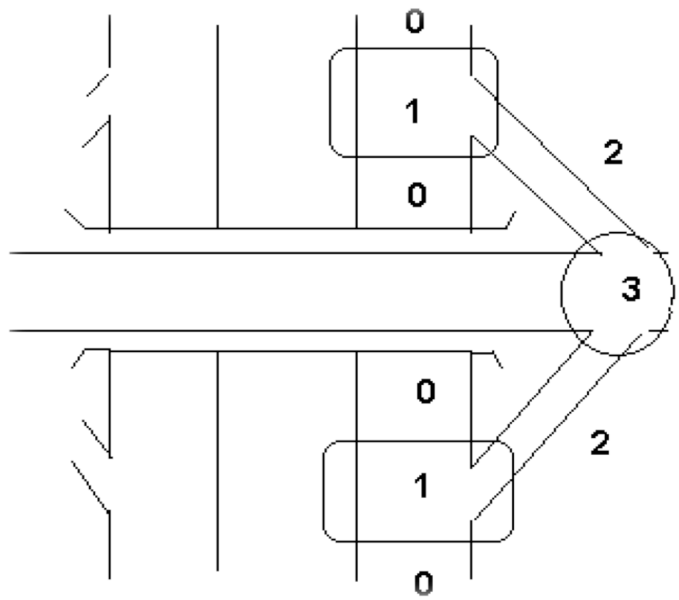


Figure 9: Ramp Section Diagram [3]

The value "0" indicates that the crash is located on the mainline before or after the ramp. The value "1" indicates that the crash is located at the intersection between the mainline and the ramp. The value "2" indicates that the crash is located in the middle portion of the ramp. The value "3" indicates that the crash is located at the intersection between the ramp and a facility other than the mainline. Hunter et al. [2], [3] noted that some of the attribute values, including Ramp Section ID values, in the crash databases are inconsistent and require interpretation. Although there is a concrete definition for this variable, its assignment to a crash in the field would be dependent upon the judgment of the police officer. This results in inconsistencies in how the values of 1 to 3 are used in the databases.

To solve this issue, a new definition of Ramp Section ID was adopted. Since the ramps of interest in this study are one-directional ramps, the Ramp Section ID values of 1 to 3 were redefined into the following definitions:

- *Ramp Section 1* – This is the portion of the ramp prior to the curved portion. It is usually the initial third of the ramp and also tangent to the upstream facility.
- *Ramp Section 2* – This is the curved portion of the ramp and contains the point of highest curvature. This is usually the middle third of the ramp.
- *Ramp Section 3* – This is the portion of the ramp after the curved portion. It is usually the last third of the ramp and also tangent to the downstream facility.

Although this definition of Ramp Section ID still depends on the judgment of the interpreter, it leaves a smaller room for error. An example of this new definition can be seen on Figure 10.

Figure 10: A Sample Interchange Ramp Divided into Ramp Sections

Accumulated Mile Log

Accumulated Mile Log is a variable from the Location Table, originally named LOC_ACC_MILELOGCUM. As discussed previously, all Interstate routes are mileposted beginning at the most westerly or southerly point. Accumulated Mile Log represents the accumulated miles of the roadway starting from the most westerly or southerly point. The Accumulated Mile Log of a roadway at a particular point resembles its milepost at that point. The only difference is the milepost would be rounded to a whole number while the Accumulated Mile Log maintains at most two decimal places. Since the variable Interchange ID also follows the milepost system, these two variables should resemble each other as well.

3.1.2 Extraction of Crash Records

The first step in preparing the data for analysis was to select the appropriate crashes for the ramps of interest. Several queries were performed in the crash databases to extract these crashes using the following variables: desired dates, County ID, Route ID, Interchange ID, and Accumulated Mile Log. This section discusses the details of how these variables were used.

3.1.2.1 Fixed Variables

Three of the five variables were used as constants such that for each individual query, a fixed value for these three variables was entered to filter the database; the three variables are desired dates, County ID, and Route ID.

Desired Dates

The desired dates are the before and after study periods, thus they are always fixed. The before period is between July 23, 2006 and April 8, 2008, while the after period is between April 15, 2008 and December 31, 2009. Both of these periods cover 626 days before and after the installation of the chevron markings. Since there are four different crash databases for the years of 2006 to 2009 (i.e. one database for yearly data), as well as a 7-day break in between the before and after periods, the desired dates were further divided into specific periods. The before period was divided into the following:

1. July 23, 2006 to December 31, 2006
2. January 1, 2007 to December 31, 2007
3. January 1, 2008 to April 8, 2008

Similarly, the after period was divided into the following:

1. April 15, 2008 to December 31, 2008
2. January 1, 2009 to December 31, 2009

County ID & Route ID

The two counties where the two interchanges of interest are located are Fulton and Cobb respectively. Therefore, there were only two County IDs used throughout the query process. The County ID of Fulton is 121 and the County ID of Cobb is 067.

Similarly, there are only three roadway facilities that needed to be examined: I75, I85, and I285. Thus, there were only three Route IDs used throughout the query process depending on which interchange is being examined. The I75-I85 interchange used two

Route IDs: 0401 for I75 and 0403 for I85. The I75-I285 interchange also used two Route IDs: 0401 for I75 and 0407 for I285.

Although there are still different values for these variables that can be used, they are fixed in the sense that there are specific values to be used in the query and no subjectivity is present when using them. As discussed in the following section, this is not the case for the other two variables out of the five.

3.1.2.2 Subjective Variables

The other two out of the five variables (i.e. Interchange ID and Accumulated Mile Log) were not used in the same manner as Desired Dates, County ID, and Route ID. For these two variables, there was some subjectivity present in using them to extract the appropriate crashes.

Interchange ID & Accumulated Mile Log

As discussed earlier, Interchange ID follows the exit numbering system of the Interstate, which was changed from the consecutive numbering system to the milepost number system in 2000. Thus, there is a possibility that the two numbering systems are still present in the crash databases as the Interchange ID variable. Prior to 2000, the I75-I285 interchange was labeled as exit 109 when traveling on I75 and exit 14 when traveling on I285. Today, this interchange is labeled as exit 259 on I75 and exit 20 on I285. In the same way, the I75-I85 interchange was labeled as 103 and today it is labeled as 251. Since I75 and I85 merge to become the Downtown Connector, only two possible Interchange IDs exist instead of the four that the I75-I285 interchange has [29], [30].

Also as discussed earlier, the Accumulated Mile Log of a highway at a particular point is essentially its milepost at that point with a precision of up to the hundredths place. It should also resemble the post-2000 Interchange ID if that particular point in the highway happens to be at an interchange. The Accumulated Mile Log is needed in order to minimize the possible error that a crash is given an incorrect Interchange ID. If this crash still has the correct Accumulated Mile Log, then it could still be examined to determine if it in fact was given the incorrect Interchange ID.

The Interchange ID is therefore used as a tool to judge which crashes are located correctly and incorrectly, as well as to judge if other crashes need to be examined based on the Accumulated Mile Log. As an example, refer to Figure 11 below. It is clear in Figure 11 that crashes with Accumulated Mile Log of 250.9 and Interchange ID of 251 refer to those that occurred on the I75-I85 interchange. It is also clear that those with Accumulated Mile Log of 249.54, 250.39, and 250.57, combined with Interchange ID of 250, refer to crashes that occur on some interchange labeled as 250. However, it is unclear where the intermediate crashes, circled in blue, are located. Although three out of the four crashes have different Interchange IDs and they are found in the middle of crashes in interchange 250, there is one crash that appears to be located in interchange 251. This raises the possibility that the other three crashes may also be located in interchange 251. In this example, the intermediate crashes would be extracted as well in order to determine whether they are located in interchange 251 (i.e. I75-I85 interchange).

THE HIGHWAY RAMPS QUERY

Microfilm	Accident Dat	LOC_COUNT	LOC_ACC_M	RMP_INTER(
85160372	2008-12-14	121	249.54	250
82910155	2008-08-02	121	249.54	250
81480284	2008-04-17	121	249.54	250
82670396	2008-07-31	121	249.56	028
82940404	2008-07-01	121	250.28	251
81480341	2008-04-17	121	250.33	016
82140201	2008-06-06	121	250.33	094
85720004	2008-10-02	121	250.39	250
85150307	2008-12-13	121	250.39	250
81810838	2008-05-13	121	250.57	250
84080406	2008-10-12	121	250.9	251
84380006	2008-11-01	121	250.9	251
84190445	2008-10-19	121	250.9	251
82840083	2008-07-23	121	250.9	251
82830067	2008-08-10	121	250.9	251
84410073	2008-10-28	121	250.9	251

Figure 11: An Example for the Use of Interchange ID and Accumulated Mile Log

3.1.2.3 Queries

Using the combination of variables discussed, 10 queries were performed to obtain the crashes for the I75-I85 interchange and 10 queries were performed to obtain those of the I75-I285 interchange. Table 3 and Table 4 show a summary of the variables used for each query.

Table 3: Variables Used for I75-I85 Interchange Queries

Study Period	Desired Dates	Route ID	County ID	Possible Interchange IDs	Accum. Mile Log
Before	7/23/2006 - 12/31/2006	0401	121	251, 103	~251
	7/23/2006 - 12/31/2006	0403			
	1/1/2007 - 12/31/2007	0401			
	1/1/2007 - 12/31/2007	0403			
	1/1/2008 - 4/8/2008	0401			
	1/1/2008 - 4/8/2008	0403			
After	4/15/08 - 12/31/2008	0401	121	251, 103	~251
	4/15/08 - 12/31/2008	0403			
	1/1/2009 - 12/31/2009	0401			
	1/1/2009 - 12/31/2009	0403			

Table 4: Variables Used for I75-I285 Interchange Queries

Study Period	Desired Dates	Route ID	County ID	Possible Interchange IDs	Accum. Mile Log
Before	7/23/2006 - 12/31/2006	0401	067	259, 109	~259
	7/23/2006 - 12/31/2006	0407		020, 014	~20
	1/1/2007 - 12/31/2007	0401		259, 109	~259
	1/1/2007 - 12/31/2007	0407		020, 014	~20
	1/1/2008 - 4/8/2008	0401		259, 109	~259
	1/1/2008 - 4/8/2008	0407		020, 014	~20
After	4/15/08 - 12/31/2008	0401	067	259, 109	~259
	4/15/08 - 12/31/2008	0407		020, 014	~20
	1/1/2009 - 12/31/2009	0401		259, 109	~259
	1/1/2009 - 12/31/2009	0407		020, 014	~20

At this stage, all crashes were obtained irrespective of their specific location on the interchange. Table 5 presents the total number of crashes obtained from the crash databases for both interchange sites and both study periods.

Table 5: Result of Queries

Interchange	Before Period	After Period	Total
I75-I85	357	209	566
I75-I285	274	166	440
Total	631	375	1,006

3.1.3 Presorting of Crashes

After obtaining all the crashes on both interchanges from the database, the next step was to group these crashes based on their ramp location within their respective interchange. Therefore, the primary objectives of this Presorting phase were (1) to sort and determine the ramps on which the crashes occurred, and (2) to divide the datasets into subgroups based on the ramp locations. In particular, the two most important subgroups are (1) the Treatment Ramp crashes and (2) the Control Ramp crashes. All other crashes not located in these two ramps are grouped in a third group.

The most accurate method to determine the ramp locations of each crash is to read through the police report for that particular crash. However, with over 1000 crashes (see Table 5 above) it would be inefficient to read each individual police report. To expedite the process, the four variables discussed earlier were used to group the crashes:

- Interchange ID
- Interchange Add-ID
- Quadrant ID
- Ramp ID

A specific combination of these variables represents a particular ramp within the interchange. Ramp Section ID was not used in this task because this variable represents where on the ramp the crash occurred, and thus would not be needed to determine what ramp in the interchange the crash occurred. This method required the assumption that the coders of the crash database were consistent when representing the location attributes of each crash. This assumption would be verified in a later stage of the methodology.

3.1.3.1 I75-I85 Interchange

In order to determine the pattern in how the four variables are being used in the database to represent different ramps, all possible combinations of these variables were extracted from the database. As shown on Table 6, there were three combinations that the databases were using.

Table 6: Location Variable Combinations Found For I75-I85 Interchange

Combination No.	Interchange ID	Interchange Add-ID	Quadrant ID	Ramp ID
1	251	O	1	1
2	251	O	4	1
3	251	O	2	1

Out of the 566 crashes extracted for this interchange, seven of them were coded using combination 1; 166 of them were coded using combination 2; 377 of them were coded using combination 3; and the remaining 16 crashes had a variety of different variable values. To presort these crashes, police reports were checked for a sample of 5% of the total number of crashes for each combination. For combination 1, since there are only 7 crashes, all 7 of their police reports were checked. For combination 2, 9 out of 166 police reports were checked. For combination 3, 19 out of 377 police reports were checked. The results of this exercise are shown below.

Table 7: Identification of Location Variable Combinations

Combination No.	Majority Location	Percentage
1	I75N and I85N – Connector Split	100% (3/3) (Note: 4/7 police reports were unavailable.)
2	I75 SB to I85 NB – Treatment Ramp	89% (8/9)
3	I85 SB to I75 NB – Control Ramp	79% (15/19)

As shown in Table 7, though there are some inconsistencies, a combination of variables generally represents a specific location on the interchange. In 89% of the checked sample, combination 2 represents the Treatment Ramp, and in 79% of the checked sample, combination 3 represents the Control Ramp. Thus, combination 2 and 3 appear to represent the Treatment and Control Ramps respectively (see Table 8). The crashes were then presorted into those in the Treatment Ramp, in the Control Ramp, and in the other remaining locations in the interchange. The results of the pre-sorting can be seen in Table 9. Their locations would be verified in a later stage of the methodology.

Table 8: Variables Used to Represent Treatment and Control Ramps (I75-I85)

	Treatment Ramp	Control Ramp
Interchange ID	251	251
Interchange Add-ID	O	O
Quadrant ID	4	2
Ramp ID	1	1

Table 9: Results of Presorting / Initial Crash Numbers (I75-I85)

	Treatment Ramp	Control Ramp	Others
Before	134	204	19
After	32	173	4

3.1.3.2 I75-I285 Interchange

A similar process to determine how the four location attributes are being used in the crash database was needed for this interchange. As shown in Table 10, there were seven different combinations that were present in the crash database. Unfortunately this exercise did not find any underlying patterns in how the variable combinations are being used to place crashes. Therefore, instead of presorting the crashes based on the combination of variables, they were presorted based on their Route ID (401 is I75 and 407 is I285) and study periods into the following four groups: (1) Route 401 Before, (2) Route 401 After, (3) Route 407 Before, and (4) Route 407 After. The results of this pre-sorting can be seen in Table 11.

Table 10: Location Variable Combinations Found For I75-I285 Interchange

Combination No.	Interchange ID	Interchange Add-ID	Quadrant ID	Ramp ID
1	259	A	1	1
2	259	A	4	1
3	259	B	2	1
4	259	O	2	2
5	259	O	3	2
6	259	O	4	1
7	014	O	4	1

Table 11: Results of Presorting for I75-I285 Interchange

	Route 401	Route 407
Before	249	25
After	149	17

3.1.4 Location Verification of Crashes

The Presorting phase divided the crashes in the raw dataset into either location groups or groups based on Route ID. If they were presorted into location groups, then that phase would have provided an initial estimation of the change in crashes in the before and after periods (e.g.

Table 9). The objective of this Location Verification phase is to verify the locations of each crash to arrive at more accurate estimates. If crashes were presorted into groups based on Route ID, then this Location Verification phase would also accurately divide these crashes into the desired location groups: the Treatment Ramp group, the Control group and a third group that contains the remaining crashes (i.e. 'Others' group).

3.1.4.1 I75-I85 Interchange

The crashes of the I75-I85 interchange were already presorted into the three location groups. This phase verifies the location of each of those crashes by checking their police reports. The results of this location verification can be seen on Table 12, Table 13, and Table 14.

Table 12: Location Verification Results for the Treatment Ramp Group (I75-I85)

Treatment Ramp	Before Period		After Period	
Located Elsewhere	21	18.3%	7	21.9%
Located Within Range of Ramp Sections	59	51.3%	16	50.0%
Sufficiently Upstream (before ramp section 1)	30	26.1%	8	25.0%
Located in HOV Lane	3	2.6%	0	0.0%
Sufficiently Downstream (after ramp section 3)	0	0.0%	1	3.1%
In Control Ramp	2	1.7%	0	0.0%
Missing Police Reports	19	-	0	-
Total number of Crashes (excluding those with missing police reports)	115	100%	32	100%

Table 13: Location Verification Results for the Control Ramp Group (I75-I85)

Control Ramp	Before Period		After Period	
Located Elsewhere	29	16.7%	22	12.7%
Located Within Range of Ramp Sections	86	49.4%	105	60.7%
Sufficiently Upstream (before ramp section 1)	54	31.0%	42	24.3%
Located in HOV Lane	0	0.0%	0	0.0%
Sufficiently Downstream (after ramp section 3)	2	1.1%	0	0.0%
In Treatment Ramp	3	1.7%	4	2.3%
Missing Police Reports	30	-	0	-
Total number of Crashes (excluding those with missing police reports)	174	100%	173	100%

Table 14: Location Verification Results for the Others Group (I75-I85)

Others	Before Period		After Period	
Treatment Ramp	0	0.0%	0	0.0%
Control Ramp	1	7.7%	0	0.0%
Located Elsewhere	12	92.3%	4	100.0%
Missing Police Reports	6	-	0	-
Total number of Crashes (excluding those with missing police reports)	13	100%	4	100%

The following findings were found from the location verification exercise for I75-I85:

1. The results show that approximately half of the crashes were within the three ramp sections: this may be seen as an error in the presorting phase or this may suggest some inconsistencies in how the crashes were recorded.
2. At least 25 percent of the crashes were identified to be sufficiently upstream of the chevron markings location (or hypothetical location in the case of the Control Ramp) that they were regarded as not relating to the sharp curve of the ramp.
3. In the case of the Treatment Ramp, a few crashes were identified to be located on the HOV lane adjacent to the ramp. These crashes were regarded as not relating to the sharp curve of the ramp.
4. A handful of crashes were identified to be sufficiently downstream of the ramp curve that they were regarded as not relating to the sharp curve of the ramp.
5. Between 12 to 22 percent of crashes were identified to have been located elsewhere (whether in the same interchange or in a different interchange) and do not fall into the categories described in numbers 1 through 4 above.
6. Some crashes were identified to have been on the Treatment Ramp, when they occurred in the Control Ramp, and vice versa.

7. In the before period, there are some police reports that are not available: 19 for the Treatment Ramp group, 30 for the Control Ramp group, and 6 for the 'Others' group. These records were not obtained in time for this study. As a result, adjustments would later on be made to reasonably account for these crashes in the analysis.
8. Lastly, from the 'Others' group, there was 1 crash found that should have been in the Control Ramp.

3.1.4.2 I75-I285 Interchange

The crashes on the I75-I285 interchange were not pre-sorted into the three desired groups that included the Treatment Ramp and Control Ramp, but into two groups based on the Route IDs. The location verification phase was then also a way to find the accurate number of crashes that occurred on the Treatment and Control ramps of this interchange. The police reports for each 440 crashes were checked in order to verify their location. The different locations found were classified into the following seven categories: Treatment Ramp, Control Ramp, Sufficiently Before/After Treatment Ramp, Sufficiently Before/After Control Ramp, Not Located on Interchange, Other Locations within Interchange and Missing Police Report. The results can be seen on Table 15 and Table 16.

Table 15: Location Verification Results for Route 401 Group (I75-I285)

Route 401	Before Period		After Period	
Treatment Ramp	21	8.5%	9	6.0%
Control Ramp	9	3.6%	5	3.4%
Sufficiently Before/After Treatment Ramp	3	1.2%	2	1.3%
Sufficiently Before/After Control Ramp	20	8.1%	15	10.1%
Not Located in Interchange	27	10.9%	21	14.1%
Other Locations within Interchange	168	67.7%	97	65.1%
Missing Police Reports	1	-	0	-
Total number of Crashes (excluding those with missing police reports)	248	100%	149	100%

Table 16: Location Verification Results for Route 407 Group (I75-I285)

Route 407	Before Period		After Period	
Treatment Ramp	2	8.0%	0	0.0%
Control Ramp	3	12.0%	3	17.6%
Sufficiently Before/After Treatment Ramp	1	4.0%	0	0.0%
Sufficiently Before/After Control Ramp	0	0.0%	0	0.0%
Not Located in Interchange	0	0.0%	0	0.0%
Other Locations within Interchange	19	76.0%	14	82.4%
Missing Police Reports	0	-	0	-
Total number of Crashes (excluding those with missing police reports)	25	100%	17	100%

The following findings were found from the location verification exercise for I75-I285:

1. The results show that there have been fewer crashes that have occurred on the Treatment and Control ramps of this interchange compared to the I75-I85 interchange.
2. At least 65 percent of the crashes in both Route IDs were found to be located somewhere else in the I75-I285 interchange and not on the Treatment and Control

ramps. These locations include other ramps in the interchange and also sections of I75 and I285 that are still within the interchange area.

3. From the Route 401 group of crashes, 11 to 14 percent of the crashes were identified to not be located in this interchange.
4. From the Route 401 group of crashes, up to 10 percent of crashes were judged to be sufficiently before or after the Treatment or Control ramp.
5. There is only 1 crash that did not have a corresponding police report. An adjustment based on this would not be made later on in the methodology, as it would be insignificant.

3.1.5 Preliminary Number of Crashes and Vehicles

The location verification phase also enabled a more accurate estimation of the number of crashes in the Treatment and Control ramps of both interchanges. The following sections discuss the steps that were taken to arrive at the preliminary number of crashes.

3.1.5.1 I75-I85 Interchange

The crash numbers for the Treatment Ramp of this interchange were obtained from three different sources. Figure 12 below shows that based on the location verification results, the three different sources are: (1) those that were correctly located to be on the Treatment Ramp, (2) those that were located on the Control Ramp but should have been on the Treatment Ramp, and (3) those that were in the 'Others' group but should have been on the Treatment Ramp. The resulting number of crashes for the Treatment Ramp are 62 crashes in the before period and 20 crashes in the after period.

Treatment Ramp	Before Period		After Period	
Located Elsewhere	21	18.3%	7	21.9%
Located Within Range of Ramp Sections	59	51.3%	16	50.0%
Sufficiently Upstream (before ramp section 1)	30	26.1%	8	25.0%
Located in HOV Lane	3	2.6%	0	0.0%
Sufficiently Downstream (after ramp section 3)	0	0.0%	1	3.1%
In Control Ramp	2	1.7%	0	0.0%
Missing Police Reports	19	-	0	-
Total number of Crashes (excluding those with missing police reports)	115	100%	32	100%

Control Ramp	Before Period		After Period	
Located Elsewhere	29	16.7%	22	12.7%
Located Within Range of Ramp Sections	86	49.4%	105	60.7%
Sufficiently Upstream (before ramp section 1)	54	31.0%	42	24.3%
Located in HOV Lane	0	0.0%	0	0.0%
Sufficiently Downstream (after ramp section 3)	2	1.1%	0	0.0%
In Treatment Ramp	3	1.7%	4	2.3%
Missing Police Reports	30	-	0	-
Total number of Crashes (excluding those with missing police reports)	174	100%	173	100%

Others	Before Period		After Period	
Treatment Ramp	0	0.0%	0	0.0%
Control Ramp	1	7.7%	0	0.0%
Located Elsewhere	12	92.3%	4	100.0%
Missing Police Reports	6	-	0	-
Total number of Crashes (excluding those with missing police reports)	13	100%	4	100%

Before	After
62	20

Figure 12: Arriving at the Preliminary Number of Crashes on the Treatment Ramp (I75-I85)

Similarly, the crash numbers for the Control Ramp of this interchange were also obtained from three different sources. Figure 13 below shows that based on the location verification results, the three different sources are: (1) those that were correctly located to be on the Control Ramp, (2) those that were located on the Treatment Ramp but should have been on the Control Ramp, and (3) those that were in the 'Others' group but should have been on the Control Ramp. The resulting number of crashes for the Control Ramp are 89 crashes in the before period and 105 crashes in the after period.

Treatment Ramp	Before Period		After Period	
Located Elsewhere	21	18.3%	7	21.9%
Located Within Range of Ramp Sections	59	51.3%	16	50.0%
Sufficiently Upstream (before ramp section 1)	30	26.1%	8	25.0%
Located in HOV Lane	3	2.6%	0	0.0%
Sufficiently Downstream (after ramp section 3)	0	0.0%	1	3.1%
In Control Ramp	2	1.7%	0	0.0%
Missing Police Reports	19	-	0	-
Total number of Crashes (excluding those with missing police reports)	115	100%	32	100%

Control Ramp	Before Period		After Period	
Located Elsewhere	29	16.7%	22	12.7%
Located Within Range of Ramp Sections	86	49.4%	105	60.7%
Sufficiently Upstream (before ramp section 1)	54	31.0%	42	24.3%
Located in HOV Lane	0	0.0%	0	0.0%
Sufficiently Downstream (after ramp section 3)	2	1.1%	0	0.0%
In Treatment Ramp	3	1.7%	4	2.3%
Missing Police Reports	30	-	0	-
Total number of Crashes (excluding those with missing police reports)	174	100%	173	100%

Others	Before Period		After Period	
Treatment Ramp	0	0.0%	0	0.0%
Control Ramp	1	7.7%	0	0.0%
Located Elsewhere	12	92.3%	4	100.0%
Missing Police Reports	6	-	0	-
Total number of Crashes (excluding those with missing police reports)	13	100%	4	100%

Before	After
89	105

Figure 13: Arriving at the Preliminary Number of Crashes on the Control Ramp (I75-I85)

3.1.5.2 I75-I285 Interchange

Figure 14 and Figure 15 show that the crashes from the Route 401 and Route 407 groups that were found to be on the Treatment and Control ramps, were added together to arrive at the preliminary number of crashes at this site. The resulting number of crashes for the Treatment Ramp are 23 in the before period and 9 in the after period. The resulting number of crashes for the Control Ramp are 12 in the before period and 8 in the after period.

Route 401	Before Period		After Period	
Treatment Ramp	21	8.5%	9	6.0%
Control Ramp	9	3.6%	5	3.4%
Sufficiently Before/After Treatment Ramp	3	1.2%	2	1.3%
Sufficiently Before/After Control Ramp	20	8.1%	15	10.1%
Not Located in Interchange	27	10.9%	21	14.1%
Other Locations within Interchange	168	67.7%	97	65.1%
Missing Police Reports	1	-	0	-
Total number of Accidents (excluding those with missing police reports)	**248**	**100%**	**149**	**100%**

Route 407	Before Period		After Period	
Treatment Ramp	2	8.0%	0	0.0%
Control Ramp	3	12.0%	3	17.6%
Sufficiently Before/After Treatment Ramp	1	4.0%	0	0.0%
Sufficiently Before/After Control Ramp	0	0.0%	0	0.0%
Not Located in Interchange	0	0.0%	0	0.0%
Other Locations within Interchange	19	76.0%	14	82.4%
Missing Police Reports	0	-	0	-
Total number of Accidents (excluding those with missing police reports)	**25**	**100%**	**17**	**100%**

Before	After
23	9

Figure 14: Arriving at the Preliminary Number of Crashes on the Treatment Ramp (I75-I285)

Route 401	Before Period		After Period	
Treatment Ramp	21	8.5%	9	6.0%
Control Ramp	9	3.6%	5	3.4%
Sufficiently Before/After Treatment Ramp	3	1.2%	2	1.3%
Sufficiently Before/After Control Ramp	20	8.1%	15	10.1%
Not Located in Interchange	27	10.9%	21	14.1%
Other Locations within Interchange	168	67.7%	97	65.1%
Missing Police Reports	1	-	0	-
Total number of Accidents (excluding those with missing police reports)	**248**	**100%**	**149**	**100%**

Route 407	Before Period		After Period	
Treatment Ramp	2	8.0%	0	0.0%
Control Ramp	3	12.0%	3	17.6%
Sufficiently Before/After Treatment Ramp	1	4.0%	0	0.0%
Sufficiently Before/After Control Ramp	0	0.0%	0	0.0%
Not Located in Interchange	0	0.0%	0	0.0%
Other Locations within Interchange	19	76.0%	14	82.4%
Missing Police Reports	0	-	0	-
Total number of Accidents (excluding those with missing police reports)	**25**	**100%**	**17**	**100%**

Before	After
12	8

Figure 15: Arriving at the Preliminary Number of Crashes on the Control Ramp (I75-I285)

3.1.5.3 Summary

A summary of the preliminary crash numbers for the four ramps can be seen on Table 17. The number of vehicles involved in these crashes was also obtained from the crash databases using the microfilm numbers of these crashes; the number of vehicles involved is also shown on Table 17. As shown, crash and vehicle numbers were significantly higher in the I75-I85 interchange. Moreover, there were missing police reports for some crashes in the I75-I85 interchange, which is addressed in the following section.

Table 17: Summary of Preliminary Crash and Vehicle Numbers

	Before Period		After Period	
	# Crashes	# Vehicles	# Crashes	# Vehicles
I75S-I85N: Treatment Ramp	62	96	20	28
I85S-I75N: Control Ramp	89	136	105	125
I285E-I75N: Treatment Ramp	23	39	9	13
I75S-I285W: Control Ramp	12	21	8	13

3.1.6 Addressing Police Report Unavailability

As discussed in Section 3.1.4, police reports were unavailable for a number of crashes that could possibly be in the four ramps being studied. There were 19 crashes that were potentially in the I75-I85 Treatment Ramp, 30 crashes that were potentially in the I75-I85 Control Ramp and 1 crash that were potentially in either ramp of the I75-I285 interchange. Since there are no physical records of these crashes, their locations could not be verified. This section describes the steps that were taken to account for these crashes.

The Presorting phase divided the crashes into different location groups, while the Location Verification phase checked to see if these crashes were in fact in their respective location groups. Since the Location Verification phase did not find a 100% match rate, a byproduct of this phase is that the proportions of crashes that were and were not on the Treatment and Control ramps were found. These same proportions, which differed between each location group, would then be used to account for the crashes that are missing police reports. Since it would be unreasonable to assume that all the crashes that are missing police reports were correctly located in their respective location groups, the assumption was made that they would have the same proportions (i.e. percentage of correct location, percentage of incorrect location, etc.) as crashes documented with police reports in their respective location groups.

3.1.6.1 Number of Crashes

As shown in Table 18 below, for the I75-I85 Treatment Ramp group, there are 59 correctly located crashes and 2 crashes that should have been in the Control Ramp. This is 51.3% and 1.7% of the total number of crashes presorted into this group. Therefore, since there are 19 crashes with missing police reports: 19 multiplied by 0.513, or approximately 10 crashes, would be considered as correctly located on the Treatment Ramp, and 19 multiplied by 0.017, or approximately 1 crash, would be considered to be on the Control Ramp.

Table 18: Distribution of Additional Crashes for I75-I85 Treatment Ramp

I75S-I85N: Treatment Ramp	Before Period		Distribute Missing	
Located Within Range of Ramp Sections	59	51.3%	19 * 0.513	10
In Control Ramp	2	1.7%	19 * 0.017	1
Missing Police Reports	19	-		
Total number of Crashes (excluding those with missing police reports)	61	53.0%		11

Similarly, for the I75-I85 Control Ramp group (Table 19), there are 86 correctly located crashes and 3 crashes that should have been in the Treatment Ramp. This is 49.4% and 1.7% of the total number of crashes presorted into this group. Therefore, since there are 30 crashes with missing police reports: 30 multiplied by 0.494, or approximately 15 crashes, would be considered as correctly located on the Control Ramp, and 30 multiplied by 0.017, or approximately 1 crash, would be considered to be on the Treatment Ramp.

Table 19: Distribution of Additional Crashes for I75-I85 Control Ramp

I85S-I75N: Control Ramp	Before Period		Distribute Missing	
Located Within Range of Ramp Sections	86	49.4%	30 * 0.494	15
In Treatment Ramp	3	1.7%	30 * 0.017	1
Missing Police Reports	30	-		
Total number of Crashes (excluding those with missing police reports)	89	51.1%		16

Lastly, there was 1 crash in the I75-I285 interchange that did not have a police report; this 1 crash was found in the Route 401 group. As shown in Table 20, this group had 21 crashes that were verified to be on the I75-I285 Treatment Ramp and 9 crashes that were verified to be on the I75-I285 Control Ramp. This is 8.5% and 3.6% of the total number of crashes presorted into this group, which are very small fractions. In fact, 168 crashes in this group were found to be in neither the Treatment Ramp nor the Control Ramp of this interchange, which is 67.7%. This suggests that there is two-thirds probability that this 1 crash would be located somewhere else in the interchange. Therefore, no additional crash was added to the I75-I285 interchange.

Table 20: Crashes Presorted into Route 401 Group in the Before Period

I75-I285: Route 401	Before Period	
Treatment Ramp	21	8.5%
Control Ramp	9	3.6%
Sufficiently Before/After Treatment Ramp	3	1.2%
Sufficiently Before/After Control Ramp	20	8.1%
Not Located in Interchange	27	10.9%
Other Locations within Interchange	168	67.7%
Missing Police Reports	1	-
Total number of Crashes (excluding those with missing police reports)	248	100%

The result of this distribution procedure is that there are 11 more crashes in the before period for the I75-I85 Treatment Ramp and 17 more crashes in the before period for the I75-I85 Control Ramp. The following table shows the finalized number of crashes in these two ramps for the I75-I85 interchange.

Table 21: Adjusted Number of Crashes in the I75-I85 Ramps

	Before Period Adjusted	After Period
I75S-I85N: Treatment Ramp	73	20
I85S-I75N: Control Ramp	106	105

3.1.6.2 Number of Vehicles

Since the number of additional crashes was estimated based on proportions as discussed in the previous section, it is unclear which of them are actually being included. Thus, although there are records in the crash databases for these crashes, there is not a way to fairly choose the 28 crash records out of the total of 49 crash records with missing police reports. Consequently, the 49 crash records in the databases were not used. Instead, the attributes for the additional crashes that were estimated were also created based on the correct proportions that are seen from their respective groups. First, this section discusses how the number of vehicles involved in these additional crashes was estimated.

As Table 17 previously showed, without the additional crashes in the before period, there are 62 crashes on the I75-I85 Treatment Ramp and 89 crashes on the I75-I85 Control Ramp, which corresponds to 96 vehicles and 136 vehicles respectively. With the additional crashes, there are 73 crashes on the Treatment Ramp and 106 crashes on the Control Ramp. Using the original rate of vehicles per crash and multiplying that with the adjusted number of crashes, an estimate for the adjusted number of vehicles was then calculated. The procedure can be seen below on Table 22.

Table 22: Calculation of Additional Vehicles

	Before Period	Adjusted-Before Period	
	Vehicles per Crash	Vehicles per Crash	No. of Vehicles
I75S-I85: Treatment Ramp	96 / 62	X / 73	(96/62)*73 = 113
I85S-I75N: Control Ramp	136 / 89	Y / 106	(136/89)*106 = 162

As shown above on Table 22, there are an additional 17 vehicles on the Treatment Ramp (i.e. 113-96 = 17) and an additional 26 vehicles on the Control Ramp (i.e. 162-89 = 26). For these crashes and vehicles, their crash attributes are also unknown. Consequently, their crash attributes were also generated for them in order to have a comparison between the before and after periods. The generation of these crash attributes is discussed in section 3.1.10.

3.1.7 Minimizing Possibility of Misplaced Crashes

There are many possibilities of error in this method of extracting crash records. Section 3.1.4 showed that crashes that were incorrectly placed on the I75-I85 and I75-I285 interchanges made up about 15% of the extracted crashes. The concern is that the reverse is also a possibility in that crashes that should be on the study ramps were misplaced on other interchanges. To check if this is a legitimate concern, a 25% sample of crashes (for years 2006 to 2009) from other potential interchanges and/or Interstate exits that have been identified were extracted and their locations were verified. If a significant percentage from the sample was found to have been misplaced and should have been on the study ramps, then a complete effort to address this would need to be done. The following subsections discuss this in further detail.

3.1.7.1 I75-I85 Interchange

According to section 3.1.4.1, there were 21 and 7 incorrectly placed crashes on the I75-I85 Treatment Ramp in the before and after periods respectively. Also, there were 29 and 22 incorrectly placed crashes on the I75-I85 Control Ramp in the before and after periods respectively. The actual locations for these crashes were determined using police reports and the findings are shown on Table 23 and Table 24.

These locations were identified to be potential locations where crashes that belong to the study ramps could be misplaced. Therefore, a 25% sample of crashes (for years 2006 to 2009) from each of these locations was extracted and their locations were verified. As seen in Table 25 below, no crashes that belong to the study ramps were found on these locations. Therefore, additional effort to check all crashes in these locations was not performed.

Table 23: Actual Locations of Crashes Misplaced on I75-I85 Treatment Ramp

	Before	After
Other locations in the same interchange	8	2
Near North Ave Exit	0	2
Near 17th/14th/10th St Exit	4	1
I75-I85 Connector Southern Split	6	1
Other	3	1
	21	7

Table 24: Actual Locations of Crashes Misplaced on I75-I85 Control Ramp

	Before	After
Other locations in the same interchange	18	13
Near North Ave Exit	0	0
Near 17th/14th/10th St Exit	2	6
I75-I85 Connector Southern Split	5	1
Other	4	2
	29	22

Table 25: Potential Interchanges/Exits for Misplaced Crashes (I75-I85)

Potential Location	Interchange ID	25% sample	No. of Crashes Found
17th/14th/10th St Exit	250/101	53	0
North Ave Exit	249/100	114	0
Cleveland Ave Exit	241/86	29	0
I75-I85 Connector Southern Split	242/87	32	0

3.1.7.2 I75-I85 Interchange

According to section 3.1.4.2, there were 27 and 21 crashes in the before and after periods respectively that were incorrectly placed at the two study ramps of this interchange. Table 26 presents the breakdown of the actual locations of these crashes.

Table 26: Actual Locations of Crashes Misplaced on I75-I285 Interchange

	Before	After
I75SB off-ramp to Cumberland Blvd	23	20
On I75SB South of Windy Hill Rd	2	0
I75S ramp to Aker Mill Rd	1	0
I75S ramp to Cobb Pkwy	0	1
On I75SB but outside of interchange area	1	0
	27	21

These locations were identified to be potential locations where crashes that belong in the study ramps could be misplaced. Since these locations are not exact interchanges or exits, three exits were chosen that represent the locations listed above. Next, a 25% sample of crashes (for years 2006 to 2009) from each of these locations was extracted and their locations were verified. Again, as Table 27 shows, no crashes were found that should have been on the study ramps.

Table 27: Potential Interchanges/Exits for Misplaced Crashes (I75-I285)

Potential Locations	Interchange ID	25% sample	No. of Crashes Found
I285/Cobb Pkwy exit	013/019	84	0
I75/Cumberland Blvd exit	108/258	18	0
I75/Windy Hill exit	110/260	110	0

3.1.8 Final Number of Crashes and Vehicles

The final number of crashes and vehicles can be seen on Table 28 below. From this, more accurate crash reduction magnitudes were calculated. For the I75-I85 interchange, the treatment ramp had a 73% reduction while the control ramp had only a 1% reduction. This finding shows that the crash reduction on the treatment ramp exists despite almost zero change in background reduction, suggesting that the chevron markings are having an influence in enhancing the safety of the facility. Meanwhile for the I75-I285 interchange, the treatment ramp had a 61% reduction while the control ramp had a 33% reduction. Again, the crash reduction on the treatment ramp still exceeds any likely expected background reduction.

Next, crashes and vehicles are analyzed. Their crash attributes would need to be obtained from the crash databases based on their microfilm numbers. However, not all of the different characteristics, or attributes, were analyzed. The next section discusses which attributes were selected for analysis.

Table 28: Summary of Final Crash and Vehicle Numbers

	Adjusted-Before Period		After Period	
	# Crashes	# Vehicles	# Crashes	# Vehicles
I75S-I85N: Treatment Ramp	73	113	20	28
I85S-I75N: Control Ramp	106	162	105	125
I285E-I75N: Treatment Ramp	23	39	9	13
I75S-I285W: Control Ramp	12	21	8	13

3.1.9 Attribute Selection

There are two possible levels of analysis: (1) crash-level analysis and (2) vehicle-level analysis. For the crash-level analysis, attributes pertaining to the crash as a whole were analyzed, which included attributes such as weather condition, accident time, and manner of collision. For the vehicle-level analysis, more specific attributes pertaining to the vehicle or the driver were analyzed, which included attributes such as age, gender, and vehicle type. The attributes selected for the analysis are found in Table 29.

Table 29: Selected Attributes for Analysis

Common Attributes	Crash-Level Attributes	Vehicle-Level Attributes
Microfilm Number Accident Date Accident Time Day of Week	Ramp Section (new definition) Crash Type Surface Condition	Age of Driver Gender of Driver Vehicle Type Driver's County of Residence

3.1.10 Crash Attributes for Additional Crashes

As discussed in section 3.1.6, there are 11 additional crashes and 17 additional vehicles to be considered in the I75-I85 Treatment Ramp, and 17 additional crashes and 26 additional vehicles to be considered in the I75-I85 Control Ramp. However, the attributes for these crashes and vehicles are not known. In order to perform the analysis, attributes were generated for these crashes based on the proportion of crashes with each attribute from the original sample of crashes. A sample calculation of how these crash attributes were generated can be seen in Appendix A. The generated attributes can be seen on Table 30-33.

Table 30: Crash-Level Attributes for Additional Crashes on I75-I85 Treatment Ramp

Crash No.	Crash Type	Ramp Section	Surface	Day of Week	Time Period of Day	No. of Vehicles
1	Angle	2	Dry	Sunday	Midnight-6am	2
2	Angle	3	Wet	Tuesday	6pm-Midnight	2
3	Rear End	1	Wet	Friday	6am-Noon	3
4	Sideswipe	1	Dry	Sunday	Noon-6pm	2
5	Sideswipe	2	Wet	Monday	6pm-Midnight	2
6	Single-vehicle	2	Dry	Sunday	Midnight-6am	1
7	Single-vehicle	2	Dry	Tuesday	Midnight-6am	1
8	Single-vehicle	2	Dry	Wednesday	Midnight-6am	1
9	Single-vehicle	2	Dry	Thursday	6am-Noon	1
10	Single-vehicle	2	Wet	Friday	Noon-6pm	1
11	Single-vehicle	2	Wet	Saturday	6pm-Midnight	1

Table 31: Vehicle-Level Attributes for Additional Crashes on I75-I85 Treatment Ramp

Vehicle No.	Crash No.	Crash Type	Gender	Age Group	Vehicle Type	Within 13-County?
1	1	Angle	F	21-25	Passenger Vehicle	Inside
2	1	Angle	M	26-30	Passenger Vehicle	Inside
3	2	Angle	F	66-70	Passenger Vehicle	Outside
4	2	Angle	M	76+	Passenger Vehicle	Outside
5	3	Rear End	F	26-30	Passenger Vehicle	Inside
6	3	Rear End	M	36-40	Passenger Vehicle	Inside
7	3	Rear End	M	56-60	Passenger Vehicle	Outside
8	4	Sideswipe	F	31-35	Passenger Vehicle	Inside
9	4	Sideswipe	F	41-45	Passenger Vehicle	Inside
10	5	Sideswipe	M	46-50	Passenger Vehicle	Inside
11	5	Sideswipe	M	61-55	Passenger Vehicle	Outside
12	6	Single-vehicle	F	16-20	Passenger Vehicle	Unknown
13	7	Single-vehicle	F	21-25	Passenger Vehicle	Inside
14	8	Single-vehicle	M	31-35	Passenger Vehicle	Inside
15	9	Single-vehicle	M	36-40	Passenger Vehicle	Inside
16	10	Single-vehicle	M	41-45	Passenger Vehicle	Inside
17	11	Single-vehicle	M	N.A	Passenger Vehicle	Outside

Table 32: Crash-Level Attributes for Additional Crashes on I75-I85 Control Ramp

Crash No.	Crash Type	Ramp Section	Surface	Day of Week	Time Period of Day	No. of Vehicles
1	Angle	3	Wet	Sunday	6pm-Midnight	2
2	Rear End	1	Dry	Monday	6am-Noon	2
3	Rear End	1	Dry	Tuesday	Noon-6pm	2
4	Rear End	1	Wet	Wednesday	Noon-6pm	3
5	Rear End	2	Wet	Friday	6pm-Midnight	3
6	Sideswipe	1	Wet	Monday	6am-Noon	3
7	Single-vehicle	2	Dry	Sunday	Midnight-6am	1
8	Single-vehicle	2	Wet	Sunday	Midnight-6am	1
9	Single-vehicle	2	Wet	Monday	6am-Noon	1
10	Single-vehicle	2	Wet	Tuesday	6am-Noon	1
11	Single-vehicle	2	Wet	Wednesday	Noon-6pm	1
12	Single-vehicle	2	Wet	Thursday	Noon-6pm	1
13	Single-vehicle	2	Wet	Thursday	Noon-6pm	1
14	Single-vehicle	2	Wet	Thursday	6pm-Midnight	1
15	Single-vehicle	2	Wet	Friday	6pm-Midnight	1
16	Single-vehicle	3	Wet	Saturday	6pm-Midnight	1
17	Single-vehicle	3	Wet	Saturday	6pm-Midnight	1

Table 33: Vehicle-Level Attributes for Additional Crashes on I75-I85 Control Ramp

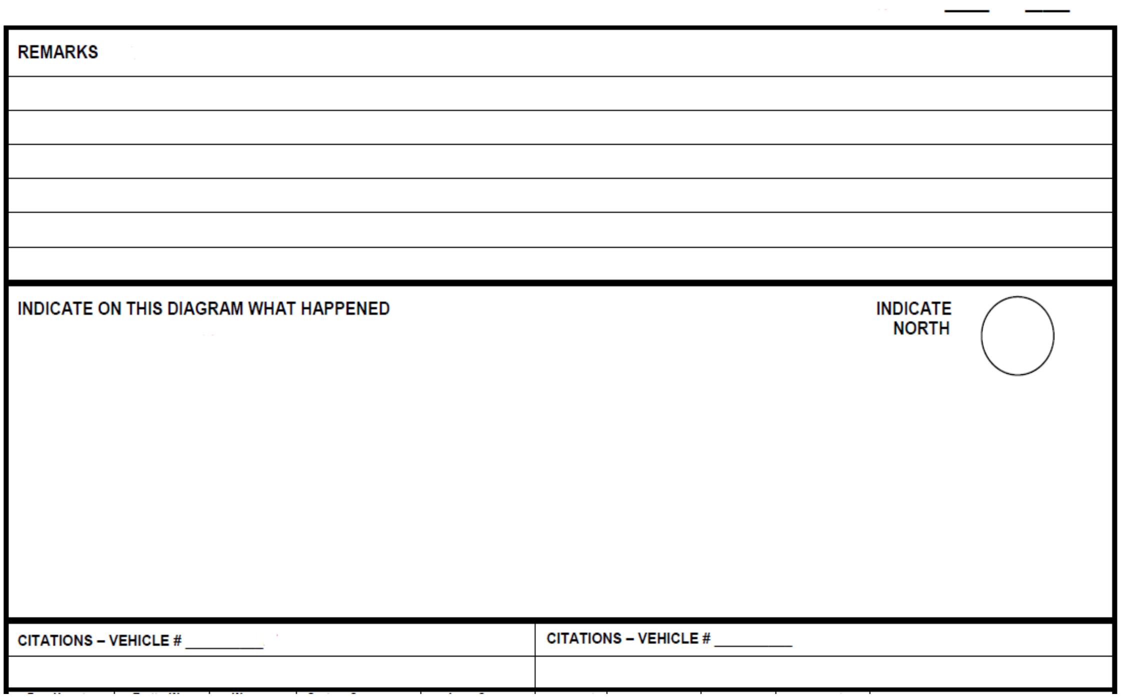
Vehicle No.	Crash No.	Crash Type	Gender	Age Group	Vehicle Type	Within 13-County?
1	1	Angle	F	16-20	Passenger Vehicle	Inside
2	1	Angle	M	26-30	Passenger Vehicle	Outside
3	2	Rear End	F	16-20	Passenger Vehicle	Inside
4	2	Rear End	M	21-25	Passenger Vehicle	Inside
5	3	Rear End	M	21-25	Passenger Vehicle	Inside
6	3	Rear End	F	26-30	Passenger Vehicle	Inside
7	4	Rear End	F	31-35	Passenger Vehicle	Inside
8	4	Rear End	M	36-40	Passenger Vehicle	Inside
9	4	Rear End	F	41-45	Passenger Vehicle	Inside
10	5	Rear End	M	41-45	Passenger Vehicle	Inside
11	5	Rear End	M	46-50	Passenger Vehicle	Inside
12	5	Rear End	M	N.A	Passenger Vehicle	Outside
13	6	Sideswipe	F	26-30	Passenger Vehicle	Inside
14	6	Sideswipe	M	36-40	Passenger Vehicle	Inside
15	6	Sideswipe	M	56-60	Heavy Vehicle	Outside
16	7	Single-vehicle	F	16-20	Passenger Vehicle	Unknown
17	8	Single-vehicle	F	21-25	Passenger Vehicle	Outside
18	9	Single-vehicle	F	26-30	Passenger Vehicle	Inside
19	10	Single-vehicle	F	31-35	Passenger Vehicle	Inside
20	11	Single-vehicle	F	36-40	Passenger Vehicle	Inside
21	12	Single-vehicle	F	61-65	Passenger Vehicle	Inside
22	13	Single-vehicle	M	16-20	Passenger Vehicle	Inside
23	14	Single-vehicle	M	21-25	Passenger Vehicle	Inside
24	15	Single-vehicle	M	31-35	Passenger Vehicle	Inside
25	16	Single-vehicle	M	46-50	Passenger Vehicle	Inside
26	17	Single-vehicle	M	N.A	Passenger Vehicle	Inside

3.2 Police Reports

The purpose of using crash police reports in the analysis was to extract any explanatory factors that would be found in the police description of the crash, which would not have been captured in the crash database record. However, since there were a number of police reports that were unavailable for this project, only those that were available were used. The steps that went into analyzing the police reports and extracting the needed information were not as complex as the steps that went into extracting the appropriate crashes from the databases. The following text presents these steps that were taken for the police reports.

3.2.1 Police Report Interpretation Procedure

The method that is used to extract explanatory factors relies largely on the human interpretation of the police reports. The interpretation is based on three specific sections of the police report: the prose account, the drawing of the crash, and the citations that were given. Figure 16 presents an example of an unfilled police report that shows the three specific sections. The prose account should provide a few sentences that describe how the event happened through the perspective of those involved and the police officer that was present. The drawing of the crash should verify the location of the crash relative to the roadway, as well as the critical maneuver that resulted in the crash. The citations should provide some background as to what the police officer thought was the underlying cause of the crash. From these three items, the researcher was able to extract some explanatory factors about the crash. Although the detail that is given by each police report may differ, the emphasis throughout this process is on giving the finest grain description possible of each crash. The process of identifying these factors generated a set of categories to identify each crash.


REMARKS

INDICATE ON THIS DIAGRAM WHAT HAPPENED

INDICATE NORTH

CITATIONS – VEHICLE # ________

CITATIONS – VEHICLE # ________

Figure 16: Sample of Page 2 of Police Report Showing Sections for Prose Account, Drawing and Citations [31]

3.2.2 Determination of Explanatory Factors

For each individual crash, the three items mentioned previously (i.e. prose account, drawing, and citations) were examined. From there, one or more explanatory factors were then given for each crash. Since each police report has different levels of details, the number of explanatory factors that a crash can have ranges from 0 to 5. If a crash has very detailed accounts based on the three sections of the police report, then 4 or 5 explanatory factors were able to be determined. If a crash has very limited accounts, or if a vehicle was found there without a driver to give an account of the accident, then 0 or maybe 1 factor were able to be determined. As shown by Table 34, a set of 18 explanatory factors were identified through this task.

Table 34: Police Report Explanatory Factors

Type of Factor	Explanatory Factor
Background	Slippery roads
	Vehicle defects
	Load problems (heavy-vehicles)
	Forced off road/lane by other vehicle
Physical	Alcohol
	Fell Asleep / Fatigue
Recognition	Inattentive / Distracted
Decision	Improper evasive maneuver
	Close following
	Deliberate risk-taking
	Excess speed (limit & conditions)
	Failure to merge
	Improper lane change
	Misjudged sharpness of curve
Performance	Failure to maintain lane
	Lost control of vehicle
	Panic / Nervous
Other	Unknown

3.2.3 Definitions of Explanatory Factors

The identification of the 18 explanatory factors was a result of the generalization of different types of descriptions found in different police reports. The generalizations are described through the following definitions:

- *Alcohol* - Driver was driving under the influence of alcohol, regardless of the fact that they accepted or rejected taking the alcohol test. This also includes those that were cited for driving under the influence per Georgia Code 40-6-391 [7], [25].

- *Improper Evasive Maneuver* - An improper evasive maneuver is any event that is taken in reaction to emergency situations that ultimately lead to a crash. This includes attempts at avoiding accident/vehicles ahead, attempts at avoiding objects on road, abruptly stopping for accident/vehicles ahead, and getting out of the way of reckless vehicles coming from behind [7].
- *Close Following* - Driver was following vehicle ahead at too close of a distance. This also includes those that mention being struck from behind, being rear-ended, being unable to suddenly stop, and those that were cited for following too close per Georgia Code 40-6-49 [25].
- *Deliberate Risk-Taking* - Driver was deliberately taking aggressive maneuvers such as making an aggressive lane change, aggressively overtaking and cutting, as well as being cited for reckless driving per Georgia Code 40-6-390 [21], [23], [24].
- *Excess Speeding (Limit & Conditions)* - Speed that is excessive relative to the traffic, roadway, ambient conditions, and speed limit. This also includes those that were cited for speeding per Georgia Code 40-6-180 [7].
- *Failure to Maintain Lane* - Driver failed to maintain lane of travel due to various reasons such as road conditions and excessive speeds. This also includes those that were cited for failure to maintain lane per Georgia Code 40-6-48.
- *Failure to Merge* - Drivers failed to yield to vehicles that had the right-of-way during merge situations, including those that were cited for failure to merge per Georgia Code 40-6-73.
- *Fatigue / Fell Asleep* - Driver fell asleep while driving [25].

- *Forced off Road/Lane by Other Vehicle* - Driver was influenced by another vehicle that came into its lane, or struck it, which caused the vehicle to run into an adjacent lane, run off the road, or struck the highway median or wall.
- *Improper Lane Change* - Driver failed to change lanes using the appropriate driving technique, such as failure to use signals and failure to check for blind side. This also includes other unsafe turning maneuvers that are cited as improper lane change per Georgia Code 40-6-123 [7].
- *Inattentive / Distracted* - Delayed recognition due to preoccupation with irrelevant thoughts, actions, or wandering of the mind [7]. This includes statements such as 'curve came up too fast', 'did not know curve was coming', 'distracted', 'looking at GPS/navigation system', 'did not see curve', 'unaware of where he/she was going', 'took eyes off road for a moment', and 'had not been watching the road'.
- *Load Problems (Heavy-Vehicle)* - Failing to secure load or failing to properly operate a vehicle with a heavy load. Unsecured loads may lead to the load falling on the road, or on another vehicle, which may cause a crash. In addition, unsecured loads may also cause the vehicle to tip over in a sharp turn. The inability of the driver of the heavy vehicle to maneuver his vehicle appropriately in the middle of other smaller traffic is also considered as a load problem [25].
- *Lost Control of Vehicle* - A loss of control is defined as the event when a vehicle runs off the road, spins out, skids, slides, or drifts without the driver's intention [24], [25].
- *Misjudged Sharpness of Curve* - Driver failed to judge the sharpness of the curve and to maneuver through the curve in the appropriate speed and manner [21], [23–

26]. This differs from inattention/distraction where the driver simply was not paying attention to the upcoming curve. In this situation, the driver is aware that a curve is coming but he/she simply did not realize that it would be as sharp as it is.

- *Panic / Nervous* - Due to the circumstances, the driver of the vehicle panics or becomes nervous. This includes improper reactions such as hitting the acceleration instead of the brakes, which ultimately leads to the driver running off the road or striking an object [7].
- *Slippery Roads* - This includes situations where the road surface is wet, oily, icy, and slick. It also includes situations where the prose account states that it is raining, the vehicle hydroplaned, or the vehicle lost traction [23–26].
- *Vehicle Defects* - In this case, the crash is due to vehicle malfunction and not due to any other factors such as surface condition or driver condition. This includes tire blowouts, tire baldness, power steering failures, brake malfunctions, and brake-light malfunctions [21], [25], [26].
- *Unknown* - The police report did not have sufficient information for determining an explanatory factor to the crash. This includes situations where the driver left the accident scene before the police arrived or the driver could not remember how the accident happened perhaps due to trauma [7–9].

CHAPTER 4: DATA ANALYSIS

Both crash-level and vehicle-level attributes were analyzed with hopes of finding the types of crashes and/or drivers that are being affected or unaffected by the chevron markings. The crash-attribute analysis utilized the 'adjusted-before' crash numbers where crashes with missing police reports were accounted for. The explanatory-factor analysis, on the other hand, utilized the original 'before' crash numbers without the additional crashes. This chapter reports the results of these analyses and discusses their implications. First, the chapter will analyze the I75-I85 interchange and then it will move on to analyze the I75-I285 interchange.

4.1 I75-I85 Interchange

4.1.1 Ramp Section

As a first step in the analysis, the locations of the crashes within their respective ramps were analyzed. Recall from section 3.1.1 that the ramp section variable was redefined due to inconsistencies in the crash databases. Ramp section 1 is the portion of the ramp prior to the curved portion, ramp section 2 is the curved portion of the ramp that contains the point of highest curvature, and ramp section 3 is the portion of the ramp after the curved portion where the ramp usually merges with another roadway. Using these definitions, the crashes on the I75-I85 Treatment Ramp were plotted, shown in Figure 17 and Figure 18.

In both study periods, the vast majority of the crashes occurred on ramp section 2 - 56 out of 73 crashes (76.7%) in the before period and 18 out of 20 crashes (90%) in the after period. Consequently, it follows that the reduction of crashes with the highest magnitude is also found in ramp section 2 with a reduction of 38 crashes (-68%).

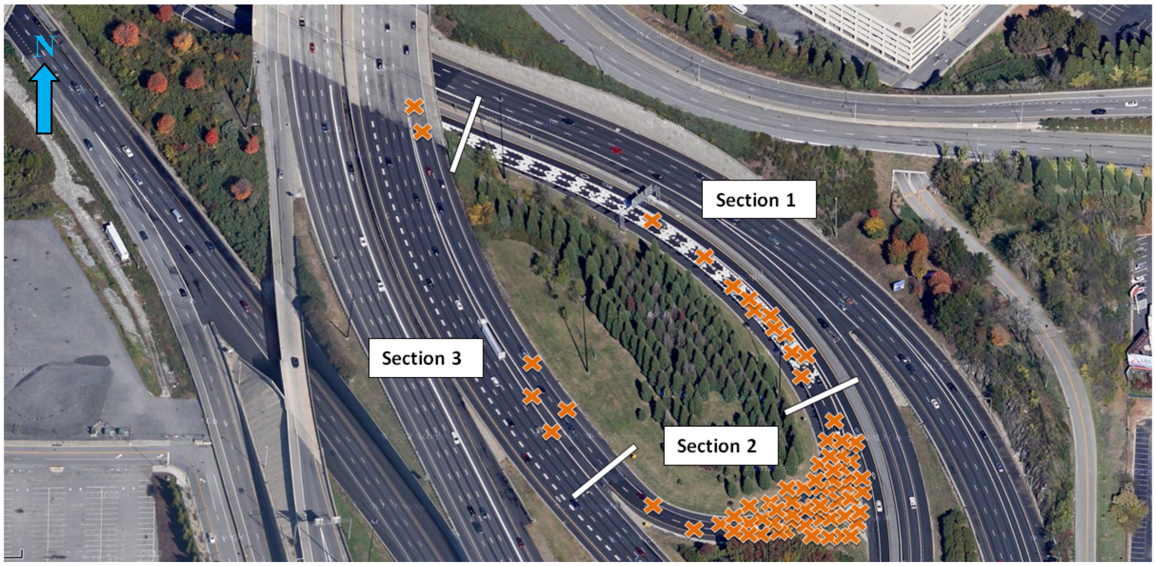


Figure 17: Location of Crashes on I75-I85 Treatment Ramp (Adjusted-Before)

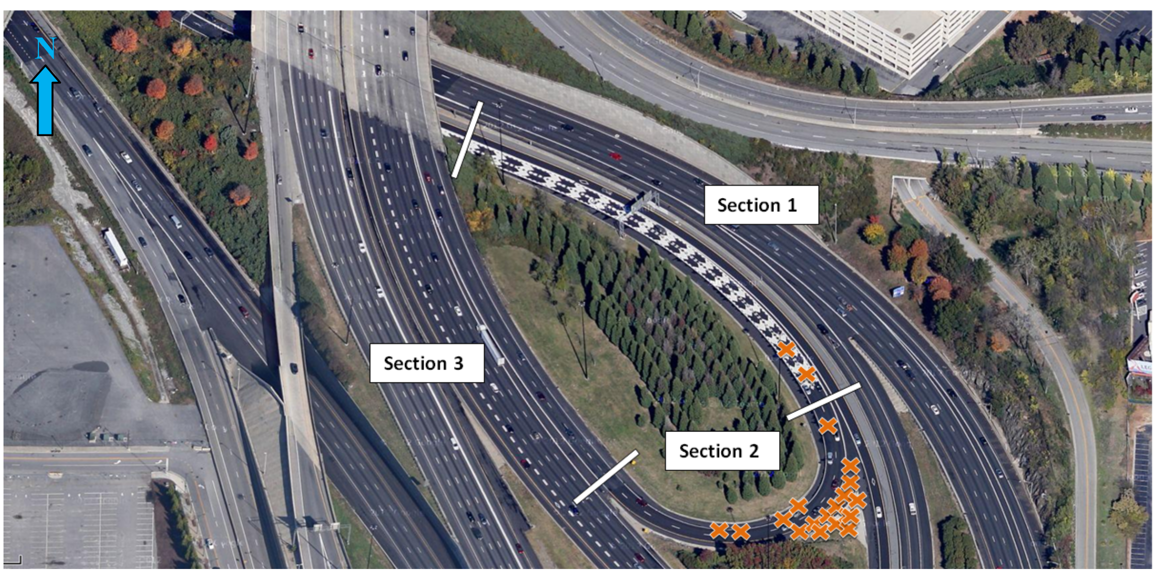


Figure 18: Location of Crashes on I75-I85 Treatment Ramp (After)

Similarly, the vast majority of crashes on the I75-I85 Control Ramp also occurred on ramp section 2 (see Appendix C). However, these crashes did not experience a decrease as on the Treatment Ramp. In fact, they increased from 63 crashes in the before period to 88 crashes in the after period, which is almost a 40% increase. This finding suggests that the crash reduction seen on ramp section 2 of the Treatment Ramp was influenced, if not directly caused, by the chevron markings.

In addition to this, ramp section 1 and 3 of the Treatment Ramp also experienced a crash reduction of 82% and 100% respectively. However, these reductions are also seen on the Control Ramp: a 63% crash reduction in ramp section 1 and a 58% crash reduction in ramp section 3. Therefore, these reductions appear to be less significant than the reduction on ramp section 2. Nonetheless, this finding also suggests that the chevron markings are having an influence in the overall reduction of crashes on the Treatment Ramp and not just the crashes on ramp section 2.

4.1.2 Crash Type

After observing that reductions of crashes occurred in all sections of the Treatment Ramp, and particularly in ramp section 2, the next step in the analysis was to analyze their crash types. Five different crash types were analyzed: angle, head on, rear end, sideswipe, and single-vehicle. Head on crashes are highly unlikely due to the one-directional nature of the ramp though there are some occurrences as will be discussed. The crash types were compared against the ramp section on which the crash occurred. Figure 19 and Figure 20 present the plots of the crashes, differentiated by type, on the

Treatment Ramp for the before and after periods. Table 35 and Table 36 accompany these figures to provide the numerical data.

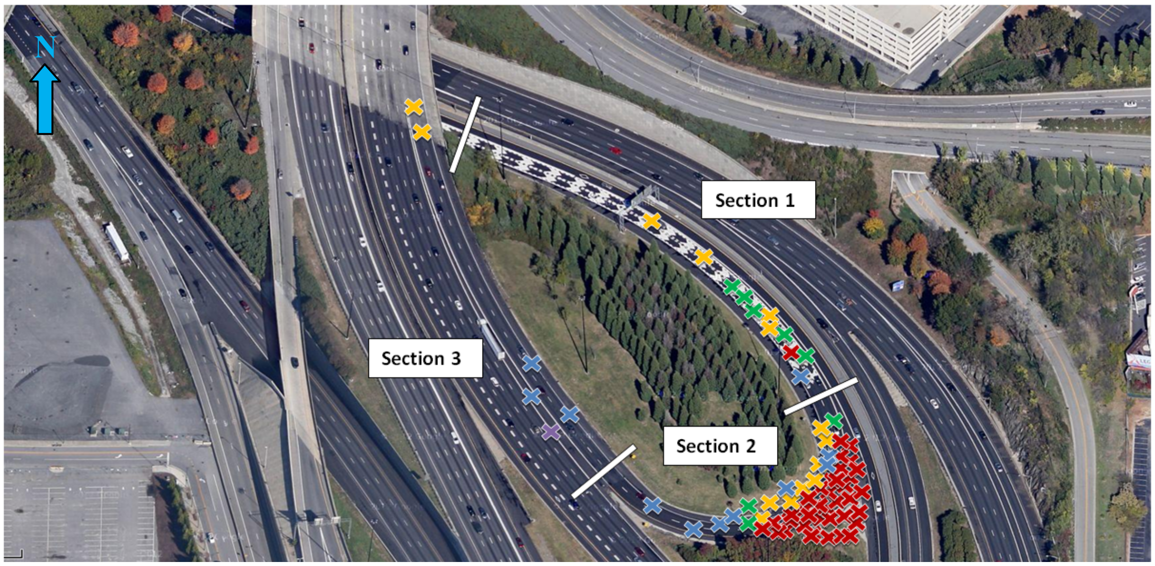


Figure 19: Plot of Crashes by Type (I75-I85 Treatment Ramp - Adjusted-Before)

Table 35: Crash Type and Ramp Section (I75-I85 Treatment Ramp - Adjusted-Before)

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Total**
Sec 1	1	0	5	4	1	**11**
Sec 2	7	0	3	8	38	**56**
Sec 3	3	1	0	2	0	**6**
Total	**11**	**1**	**8**	**14**	**39**	**73**

As shown above, the majority of crashes that occurred on ramp section 2 are in fact single-vehicle crashes. Similarly, in the after period (see Figure 20 and Table 36), the majority of crashes that occurred on ramp section 2 are also single-vehicle crashes. As shown on Table 35, there is 1 head on crash located on ramp section 3. The mechanism of this crash was a vehicle loss of control leading to a spin out and a head on crash with another vehicle; it was not because the vehicle was traveling in the wrong direction.

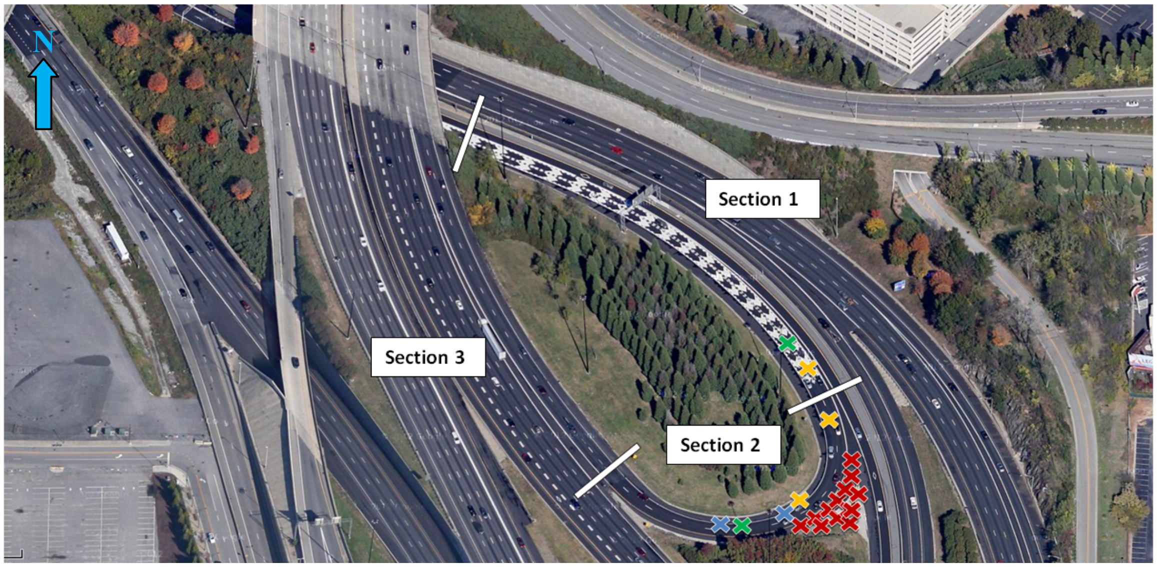


Figure 20: Plot of Crashes by Type (I75-I85 Treatment Ramp - After)

Table 36: Crash Type and Ramp Section (I75-I85 Treatment Ramp - After)

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Total**
Sec 1	0	0	1	1	0	**2**
Sec 2	2	0	1	2	13	**18**
Sec 3	0	0	0	0	0	**0**
Total	**2**	**0**	**2**	**3**	**13**	**20**

In the overall number of crashes per type, the highest reduction in magnitude is experienced by single-vehicle crashes, which had a reduction of 26 crashes or 67% (i.e. from 39 to 13). Other crash types were also reduced: sideswipe crashes had a reduction of 11 crashes or 79%, rear end crashes had a reduction of 6 crashes or 75%, and angle crashes had a reduction of 9 crashes or 82%. Although the magnitude of the reduction is largest for single-vehicle crashes, these findings suggest that the chevron markings are addressing all crash types. In contrast, the Control Ramp (see Appendix C) had increases in single-vehicle crashes of 18 (26%) and in single-vehicle crashes on ramp section 2 of 22 (39%) while other crash types and locations decreased. This suggests that perhaps there is a different cause for single-vehicle crashes on the Control Ramp than on the Treatment Ramp. These questions are noted as the analysis continues to other important variables.

4.1.3 Day of Week

Day of week was the next variable to be analyzed. Figure 21 and Figure 22 present the distribution of crashes by day of week in the Treatment Ramp for both the before and after periods. The distribution shows that the peak frequency of crashes in the before period is on Sundays. Mondays and Wednesdays are the days with the lowest crash frequencies while Tuesdays have a surprisingly high number of crashes. Crashes appear to reach peak frequency towards the weekend, which suggests that they are related to weekend travel. In fact, 40 out of the 73 crashes in the before period did occur between Fridays and Sundays. This general trend is also seen in the Control Ramp crashes (see Appendix C). However, the distribution of crashes in the after period shows that reductions are seen across all days; there is an average reduction of 66%. This suggests that the effects of the chevron markings are not limited to any specific day or range of days.

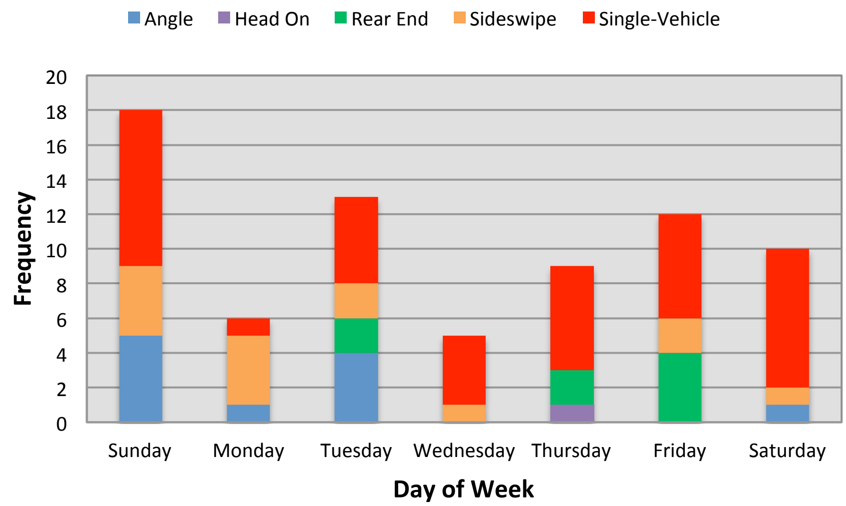


Figure 21: Crash Type and Day of Week (I75-I85 Treatment Ramp - Adjusted-Before)

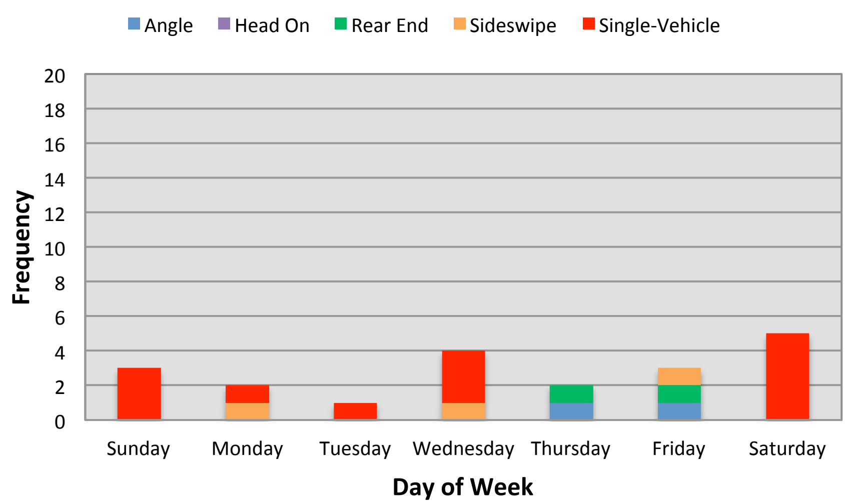


Figure 22: Crash Type and Day of Week (I75-I85 Treatment Ramp - After)

4.1.4 Time of Day

Next, the distribution of crashes across different times of the day was analyzed. Figure 23 and Figure 24 show the time of day distributions for the Treatment Ramp. It appears that the peak frequency of crashes, as well as the peak frequency of single-vehicle crashes, is in the Midnight-6am time range. Moreover, the bulk of the crashes in this time range occurred between Fridays and Sundays (see Appendix B) which supports the theory that these crashes are related to weekend travel. In contrast, crashes in the Control Ramp appear to increase throughout the day (see Appendix C), and this pattern is seen in both the before and after periods. Crash frequency is at its lowest during the Midnight-6am time period, and it gradually increases until the following midnight. In the after period, it appears that all crash types benefitted from the chevron markings though single-vehicle crashes benefitted the most. All of the four time periods also had major crash reductions: -75% for Midnight-6am, -93% for 6am-Noon, -75% for Noon-6pm and -53% for 6pm-Midnight. This shows that the effects of the chevron markings do not appear to be limited to certain times of day.

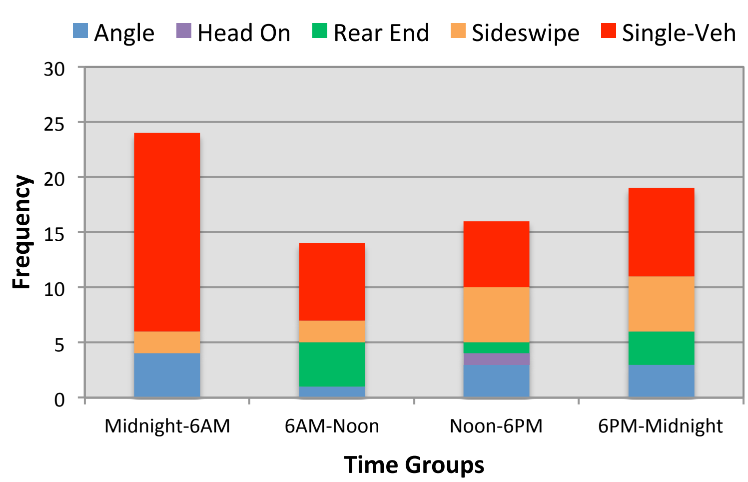


Figure 23: Crash Type and Time of Day (I75-I85 Treatment Ramp - Adjusted-Before)

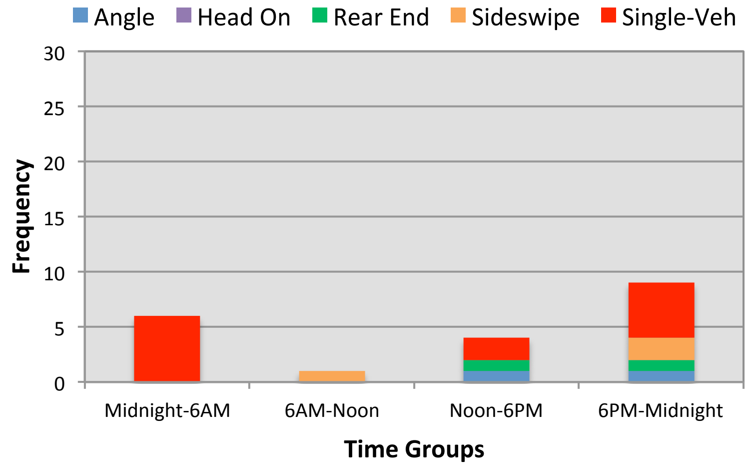


Figure 24: Crash Type and Time of Day (I75-I85 Treatment Ramp - After)

4.1.5 Surface Conditions

An analysis on the effects of wet and dry surface conditions was also performed. Figure 25 and Figure 26 show the surface condition distributions for the Treatment Ramp categorized per crash type. In the before period, the total number of crashes on dry conditions (38 crashes) and wet conditions (35 crashes) were almost equal. Single-vehicle crashes were more prevalent on dry conditions (i.e. 26 in dry conditions and 13 in wet conditions). In contrast, these trends are not seen on the Control Ramp (see Appendix C). In the before period, 80% of crashes were on wet surface conditions. In the after period, 89% of crashes were on wet surface conditions. From this, surface conditions appear to play a more significant role in crash events on the Control Ramp. This idea will be further discussed later in this chapter.

The high number of crashes in wet surface conditions, especially in the Control Ramp, suggests that this type of crash was overrepresented in the sample. Hourly precipitation data at the DeKalb-Peachtree Airport in Atlanta, recorded by the National

Oceanic and Atmospheric Administration (NOAA) [32], was analyzed to calculate the percentage of hours where there was precipitation in the before and after periods. The results can be seen in Table 37. The data was grouped into 2 categories: hours with precipitation including 'trace' and hours with precipitation excluding 'trace'. Trace is a variable used by NOAA that represents the existence of some precipitation that was not measurable. Table 37 shows that only 9% of the total hours in the before period had precipitation and only about 11% of the total hours in the after period had precipitation, if accounting for 'trace'. These rates are very low and considering that precipitation does not always result in wet roadway surfaces, the likelihood of having wet roadway surfaces can be assumed to be even lower. Since the percentage of crashes in wet surface conditions is higher than these rates, wet surface crash types likely are overrepresented in the sample and an important causation factor to crashes on these ramps.

Table 37: Percentage of Hours with Precipitation at DeKalb-Peachtree Airport Station [32]

Time Period		**Before**			**After**		
		Hours in Period	Hours with Precip. (incl. 'Trace')	Hours with Precip. (excl. 'Trace')	Hours in Period	Hours with Precip. (incl. 'Trace')	Hours with Precip. (excl. 'Trace')
12am-6am	Hours	3756	295	192	3756	351	240
	%	**-**	**7.85**	**5.11**	**-**	**9.35**	**6.39**
6am-12pm	Hours	3756	329	219	3756	420	291
	%	**-**	**8.76**	**5.83**	**-**	**11.18**	**7.75**
12pm-6pm	Hours	3756	344	219	3756	463	279
	%	**-**	**9.16**	**5.83**	**-**	**12.33**	**7.43**
6pm-12am	Hours	3756	374	233	3756	402	275
	%	**-**	**9.96**	**6.2**	**-**	**10.7**	**7.32**
Total	Hours	15024	1342	863	15024	1636	1085
	%	**-**	**8.93**	**5.74**	**-**	**10.89**	**7.22**

However, all crashes, wet or dry surface conditions, were reduced by large percentages in the after period. Crashes on dry conditions were reduced by 68% to 12 crashes, crashes on wet conditions by 77% to 8 crashes, and single-vehicle crashes reduced by 67% to 13 crashes. Moreover, all other types of crashes appear to be reduced significantly as well. This suggests that the chevron markings are reducing crashes under both types of surface condition. It does not appear that the chevron markings are limited to one surface condition.

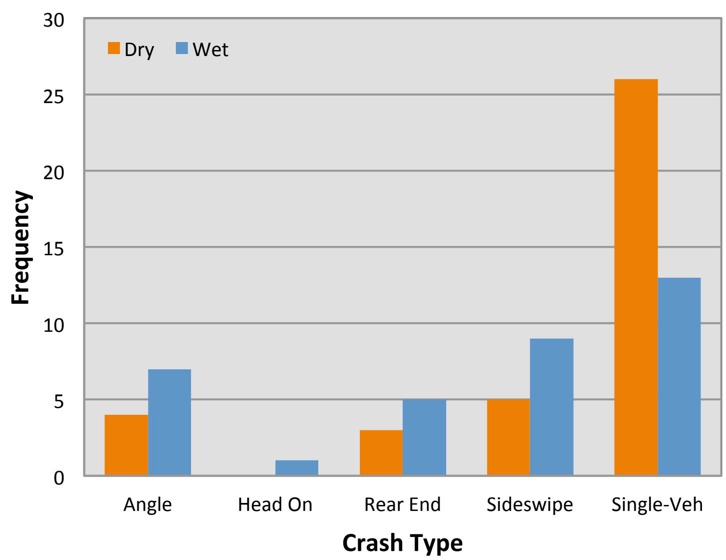


Figure 25: Crash Type and Surface Condition (I75-I85 Treatment Ramp - Adjusted-Before)

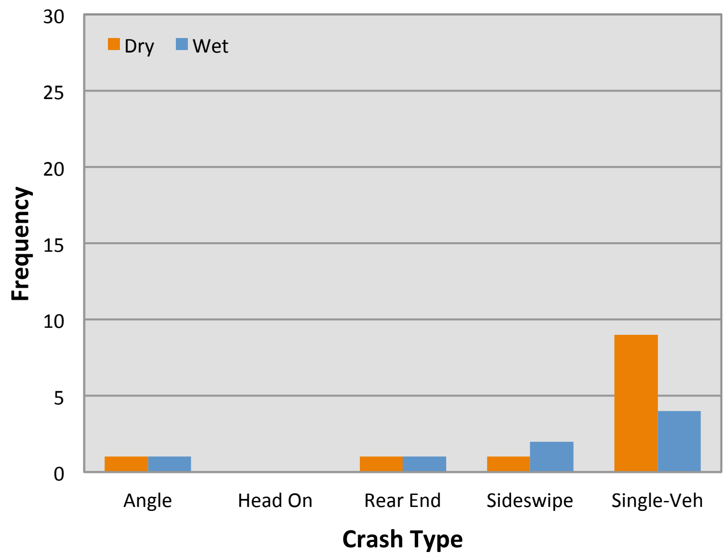


Figure 26: Crash Type and Surface Condition (I75-I85 Treatment Ramp - After)

4.1.6 Vehicle Type

Next, the analysis will dive into vehicle-level attributes starting with vehicle type. Table 38 and Table 39 present the vehicle compositions of the before and after crashes in the Treatment and Control ramps respectively. In the Treatment Ramp, over 96% of the vehicles involved in the before period were passenger vehicles which include passenger cars, vans, SUVs, and pickup trucks. This dominance is also seen in the after period as well as in the Control Ramp. This finding is consistent with the restriction of heavy-vehicles inside the perimeter (i.e. region inside I285) as shown on Figure 27. In the Treatment Ramp, passenger vehicles experienced a reduction of 76% while in the Control Ramp they experienced a reduction of 22%. Thus, even if there is a background reduction of passenger vehicles of around 20% that is not attributable to the chevron markings, there is still more than a 50% reduction that may be attributable to the chevron markings. Other vehicle types were also greatly reduced but since their numbers were limited, this observation should be taken with caution.

Figure 27: Signs on I85 Southbound Showing Heavy-Vehicle Restriction [4]

Table 38: Composition of Vehicles Involved in Crashes (I75-I85 Treatment Ramp)

Vehicle Type	Adjusted-Before	After	Change	% Change
Passenger Vehicle	109	26	-83	-76%
Heavy Vehicle	2	1	-1	-50%
Other	2	1	-1	-50%
Total	113	28	-85	-75%

Table 39: Composition of Vehicles Involved in Crashes (I75-I85 Control Ramp)

Vehicle Type	Adjusted-Before	After	Change	% Change
Passenger Vehicle	157	123	-34	-22%
Heavy Vehicle	3	2	-1	-33%
Other	2	0	-2	-100%
Total	162	125	-37	-23%

4.1.7 Age Distribution

The age distribution of drivers in the I75-I85 Treatment Ramp was also analyzed to find out whether the chevron markings had an influence on specific age groups or on the entire driving population in general. Figure 28 and Figure 29 show the age distribution of the drivers involved in crashes on the Treatment Ramp for the before and after period.

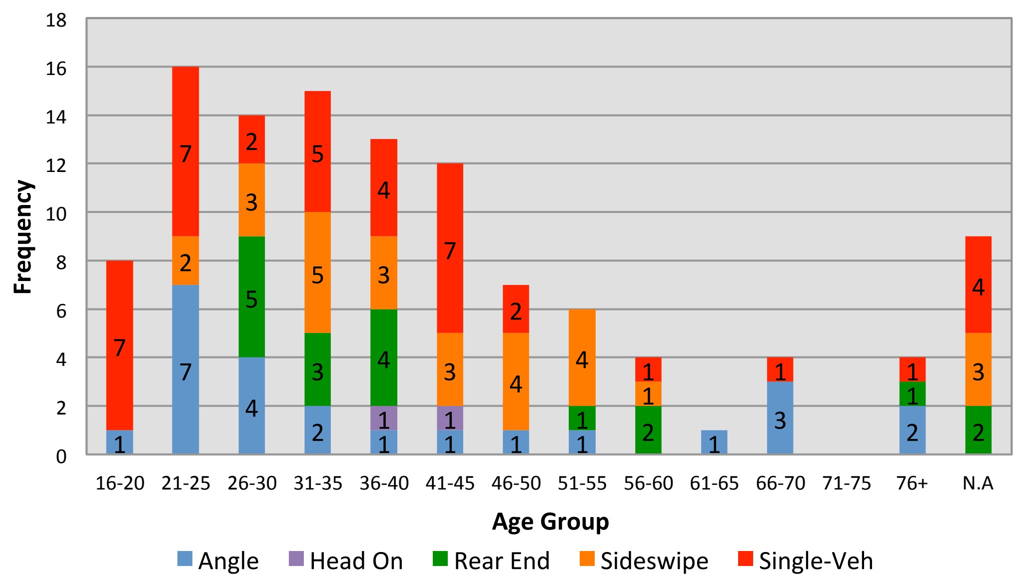


Figure 28: Age Distribution and Crash Type (I75-I85 Treatment Ramp - Adjusted-Before)

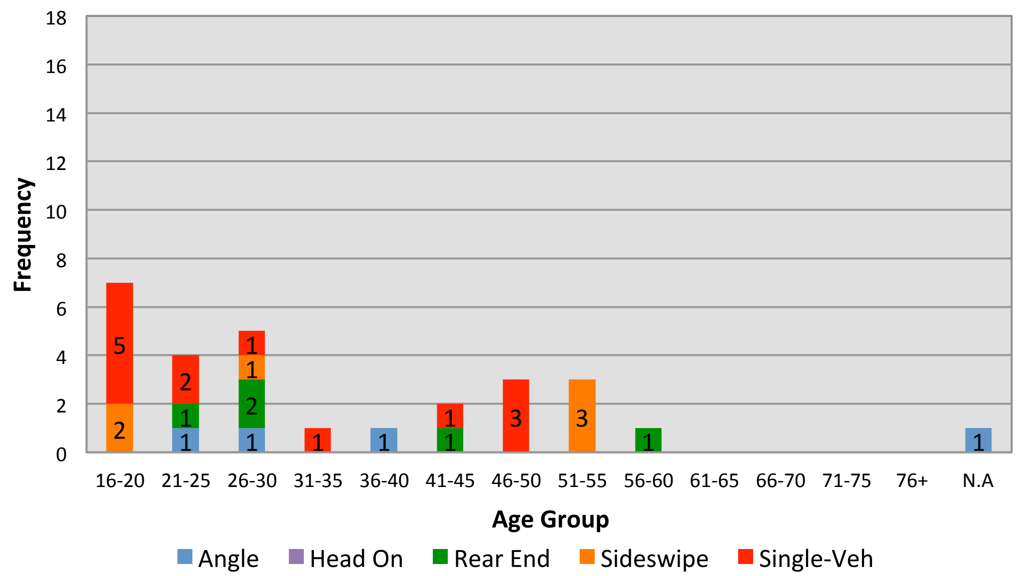


Figure 29: Age Distribution and Crash Type (I75-I85 Treatment Ramp - After)

All age groups appear to have experienced a reduction in crashes. One age group in particular, however, did not experience as large a crash reduction as other age groups: age group 16-20. These younger drivers only had a reduction of 1 crash, which is a 15% reduction but arguably not significant. On the other hand, other age groups experienced an average reduction of 75%. In the Control Ramp (see Appendix C), drivers in the age group 21-25 increased in the after period while other age groups appeared to have either decreased or stayed the same. This is a finding that was not seen on the Treatment Ramp. This suggests that the chevron markings were effective in reducing crashes for drivers in all age groups except for 16-20, although future efforts will need to confirm the statistical significance of this finding.

4.1.8 Gender Distribution

The gender distribution of drivers in the I75-I85 Treatment Ramp was also analyzed to find out whether the chevron markings had an influence on a specific gender or on the entire driving population in general. Figure 30 and Figure 31 below show the gender distribution of the drivers involved in crashes on the Treatment Ramp for the before and after period.

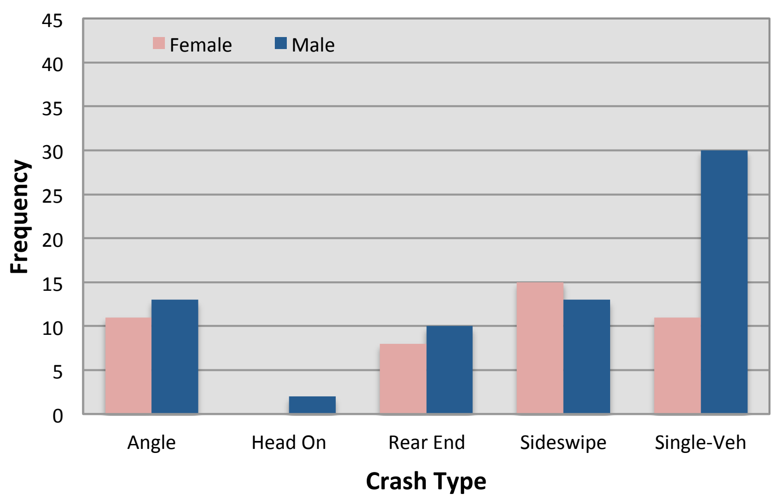


Figure 30: Gender and Crash Type (I75-I85 Treatment Ramp – Adjusted-Before)

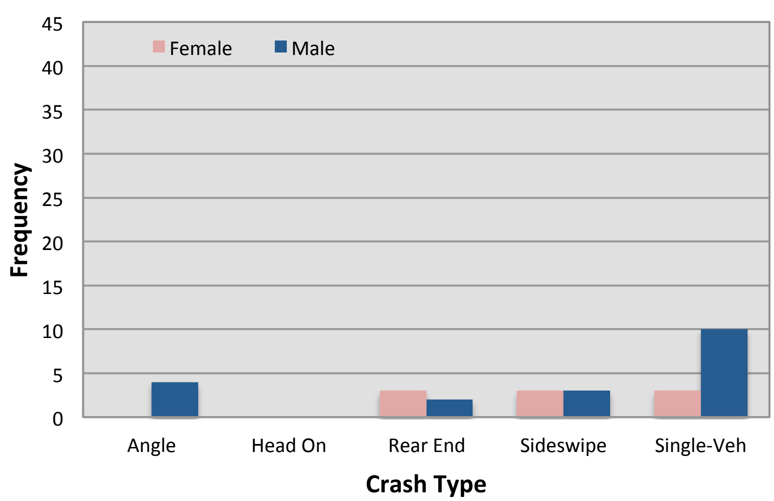


Figure 31: Gender and Crash Type (I75-I85 Treatment Ramp - After)

As expected, male drivers are overrepresented in the overall sample. Between 2006 and 2009, virtually 50% of licensed drivers are male [5]. From the before data, 60% of the drivers involved in the crashes in the before period were male and 40% were female. Male drivers were more involved in single-vehicle crashes at 73% than female drivers at 27%, but both groups were approximately even in other crash types. The same trend is seen in the after period: 68% of the drivers involved in crashes were male and 32% were female, and male drivers were more involved in single-vehicle crashes at 77% to female drivers at 23%. On the other hand, the Control Ramp had gender distributions that were closer to even (see Appendix C). In the before period, about 55% of the drivers involved in crashes were male and 45% were female. In the after period, this distribution became even at 50%. This shows that on the Treatment Ramp, male drivers were likely overrepresented to a greater extent.

However, the findings do not suggest that the chevrons work better on a particular gender group. Large reductions were seen in both male and female drivers: 80% reduction for female drivers and 72% reduction for male drivers.

4.1.9 Driver Familiarity

Driver familiarity with the area is another variable that can influence a crash. In analyzing driver familiarity, it was initially hypothesized that the drivers that are most vulnerable to a sharp curve, or any type of hazard that violates driver expectancy, would be those that are not familiar with the area. Drivers that pass through the ramp on a regular basis should not be as vulnerable as drivers that have never been on the ramp. For the analysis of driver familiarity, the county of residence of drivers was used a surrogate variable. For this purpose, unfamiliarity with the area is defined as a having a county of residence outside a fixed region of Atlanta. A study on the geographic and demographic profiles of commuters in Atlanta utilized a 13-county metro Atlanta region to assess the effects of converting fixed automotive operating costs into mileage- and congestion-based operating costs on commuters [33]. The 13-county region included Cherokee, Clayton, Cobb, Coweta, DeKalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Henry, Paulding, and Rockdale. These counties were chosen with the reason that they are home to many drivers who frequently use the highways in a suburb-to-central business district (CBD) commute pattern. As part of the procedure, the project collected 5,692 distinct license plates on several sites around Atlanta. In the analysis, it was found that 89.5% of the license plates were from the 13-county metro Atlanta area [33]. Therefore, the same 13-county metro Atlanta region was used in the analysis of driver familiarity. Figure 32 and Figure 33 present the distribution of driver familiarity in terms of different crash types on the Treatment Ramp for the before and after periods.

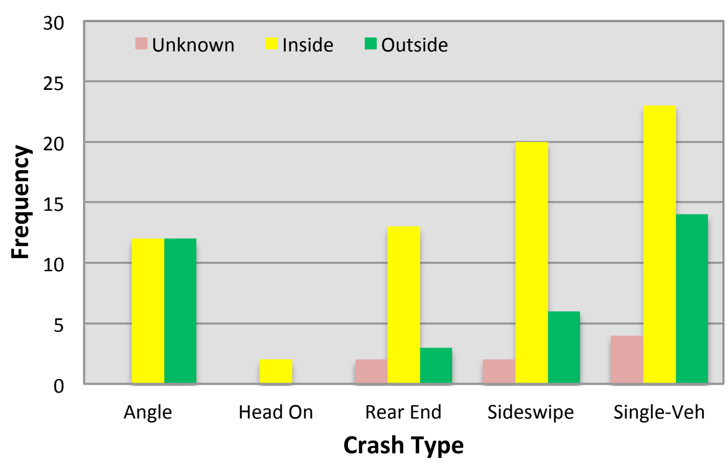


Figure 32: County of Residence and Crash Type (I75-I85 Treatment Ramp - Adjusted-Before)

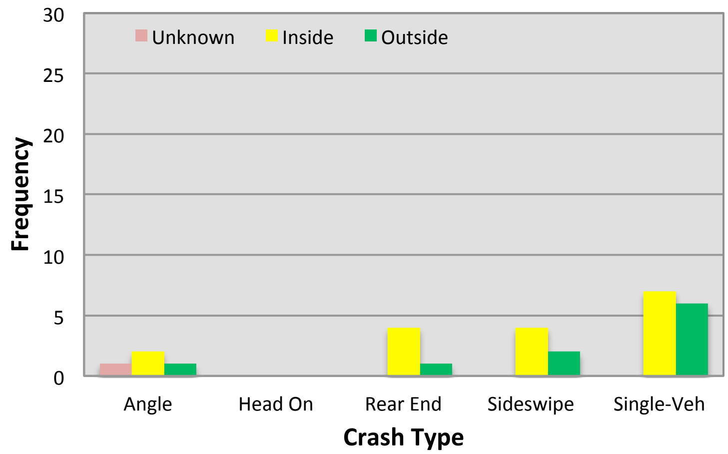


Figure 33: County of Residence and Crash Type (I75-I85 Treatment Ramp - After)

The analysis shows that in the before period, 62% of drivers involved in the crashes (70 out of 113 drivers) were from counties inside of the 13-county area. Similarly in the after period, 61% of drivers involved in the crashes (17 out of 28 drivers) were from counties inside of the 13-county area. This finding suggests that the initial hypothesis was partially incorrect; drivers familiar with the area are still very much vulnerable to the sharp curve. However, it is important to note that drivers that live outside of the 13-county area are overrepresented in both periods: 31% of drivers in the before period and 36% of drivers in the after period. Meanwhile, Nelson et al. [33] reported that only 10.5% of their license plate data were of counties outside of the 13-county area. In contrast, unfamiliar drivers on the Control Ramp (Appendix C) only made up about 15% and 19% of the drivers involved in the before and after periods respectively. Although this shows that there is also a slight overrepresentation of unfamiliar drivers on the Control Ramp, over 80% of the drivers resided inside the 13-county boundary. Therefore, the overrepresentation of unfamiliar drivers on the

Treatment Ramp does suggest that they are more vulnerable to the sharp curve than familiar drivers.

In the after period, large reductions were observed for both groups: drivers familiar with the area experienced a reduction of 76% while drivers unfamiliar with the area experienced a reduction of 71%. This suggests that the chevron markings appear to be addressing both types of drivers.

4.1.10 Explanatory Factors

The results of the I75-I85 police report analysis is presented in this section. The purpose of using the explanatory factors is to find support for the trends that are seen from the attributes that have been analyzed. Table 40 shows the explanatory factors found for the Treatment Ramp crashes. In the before period, a large percentage of the crashes reported that there was a loss of control of the vehicles: 66%. About 30% of the crashes also involved speeding as well as the failure to maintain lane. These three factors support the finding the single-vehicle crashes are the most prevalent on this ramp and they also offer a mechanism to these crashes. It appears that the mechanism of single-vehicle crashes on this Treatment Ramp involves drivers that are coming into the curve at excessive speeds that cause them to not be able to maintain their lanes or lose control of their vehicles. At the event that no other vehicles were nearby, it appears that this would result in a single-vehicle crash. At the event that there are other vehicles nearby, it appears that this would result in an angle or sideswipe crash as well as in forcing another vehicle off the road. The explanatory factors also offer a number of suggestions as to why the drivers were frequently coming in at high speeds including alcohol-use, fatigue, inattentive/distracted, misjudged sharpness of curve, panic/nervous, and vehicle defects.

Table 40: I75-I85 Treatment Ramp Explanatory Factors

Police Report Explanatory Factor	Before		After		Change
	#	%	#	%	
Alcohol	6	9.7	0	0.0	-6
Avoidance maneuver	2	3.2	1	5.0	-1
Close following	7	11.3	1	5.0	-6
Deliberate risk-taking	2	3.2	2	10.0	0
Excess speed (limit & conditions)	19	30.7	3	15.0	-16
Failure to maintain lane	20	32.3	6	30.0	-14
Failure to merge	1	1.6	0	0.0	-1
Fell asleep	1	1.6	0	0.0	-1
Forced off road/lane by other vehicle	5	8.1	1	5.0	-4
Improper lane change	3	4.8	1	5.0	-2
Inattentive/distracted	6	9.7	3	15.0	-3
Load problems (heavy-vehicle)	2	3.2	0	0.0	-2
Lost control of vehicle	41	66.1	13	65.0	-28
Misjudged sharpness of curve	1	1.6	1	5.0	0
Panic/nervous	1	1.6	0	0.0	-1
Slippery roads	5	8.1	1	5.0	-4
Vehicle defects	1	1.6	0	0.0	-1
Unknown	2	3.2	0	0.0	-2

Section 4.1.4 analyzed the crashes in terms of time of day and found that the peak crash frequency as well as the peak single-vehicle crash frequency occurred between midnight and 6 a.m., which suggests that drivers coming home from social activities may be a factor. Table 40 shows that alcohol was present in almost 10% of the crashes, which is a small percentage compared to how many crashes occurred between midnight and 6

a.m. Therefore, alcohol-use alone is not likely the primary factor in the majority of crashes on the Treatment Ramp. In the after period, the effects of the chevron markings can be seen across all of the factors. Alcohol-use as a factor was eliminated. Inattention and distraction as a factor was reduced. Crashes from slippery roads were also reduced. In addition, the largest reductions are seen in the multiple factors that highlight the causes of the crashes: excessive speeds, loss of control, and failure to maintain lane.

In the Control Ramp, there are different explanatory factors as shown on Table 41. The high percentages of losing control, excessive speed and failure to maintain lane still support that single-vehicle crashes are the major crash type on the ramp. However unlike in the Treatment Ramp, slippery roads are a bigger factor on this ramp (24%) compared to the 8% on the Treatment Ramp. This was also evident from the surface condition analysis at an even higher degree: 80% of crashes in the before period and 89% of crashes in the after period were on wet surface conditions. This discrepancy suggests that drivers and police officers generally do not include surface conditions in the actual description of the crash event but simply list them in the weather category box of the police report. Whether or not this means that the drivers and officers believe wet roads to be a factor in their crashes is uncertain.

Table 41: I75-I85 Control Ramp Explanatory Factors

Police Report Explanatory Factor	Before		After		Change
	#	%	#	%	
Alcohol	0	0.0	1	1.0	+1
Avoidance maneuver	5	5.6	9	8.6	+4
Close following	17	19.1	13	12.4	-4
Deliberate risk-taking	1	1.1	1	1.0	0
Excess speed (limit & conditions)	16	18.0	24	22.9	+8
Failure to maintain lane	11	12.4	0	0.0	-11
Failure to merge	0	0.0	0	0.0	0
Fell asleep	0	0.0	0	0.0	0
Forced off road/lane by other vehicle	1	1.1	3	2.9	+2
Improper lane change	2	2.3	1	1.0	-1
Inattentive/distracted	1	1.1	1	1.0	0
Load problems (heavy-vehicle)	0	0.0	0	0.0	0
Lost control of vehicle	64	71.9	93	88.6	+29
Misjudged sharpness of curve	0	0.0	0	0.0	0
Panic/nervous	1	1.1	1	1.0	0
Slippery roads	21	23.6	23	21.9	+2
Vehicle defects	3	3.4	4	3.8	+1
Unknown	2	2.3	0	0.0	-2

4.2 I75-I285 Interchange

4.2.1 Ramp Section

For the I75-I285 interchange, again the first variable that was analyzed was ramp section. The crash plots can be seen on Figure 34 and Figure 35. Similar to the I75-I85 Treatment Ramp, the highest number of crashes for this ramp is also found on ramp section 2: 10 out of 23 crashes (43%) in the before period and 6 out of 9 crashes (67%) in the after period. In the other ramp sections, the before period had 7 crashes on ramp section 1 and 6 crashes on ramp section 3 while the after period had 2 crashes on ramp section 1 and 1 crash on ramp section 3. Since the crash numbers are so small, it is difficult to conclude that the most vulnerable ramp is ramp section 2, or any other ramp section for that matter. Nonetheless, the crash numbers on each ramp section decreased in the after period: section 1 experienced a reduction of 5 crashes (71%), section 2 experienced a reduction of 4 crashes (40%), and section 3 experienced a reduction of 5 crashes (83%). This suggests that the chevron markings are having an overall effect on the likelihood of crashes.

In the same way, the crash locations for the I75-I285 Control Ramp were plotted (see Appendix D). However, the crash numbers for this ramp are even smaller and thus, it is also difficult to conclude if any ramp section is more vulnerable than the others. The crash numbers on this ramp also decreased by an overall rate of 38%. Therefore, although the chevron markings are reducing crashes on the I75-I285 Treatment Ramp, perhaps they are not having the same impact as they did on the I75-I85 Treatment Ramp.

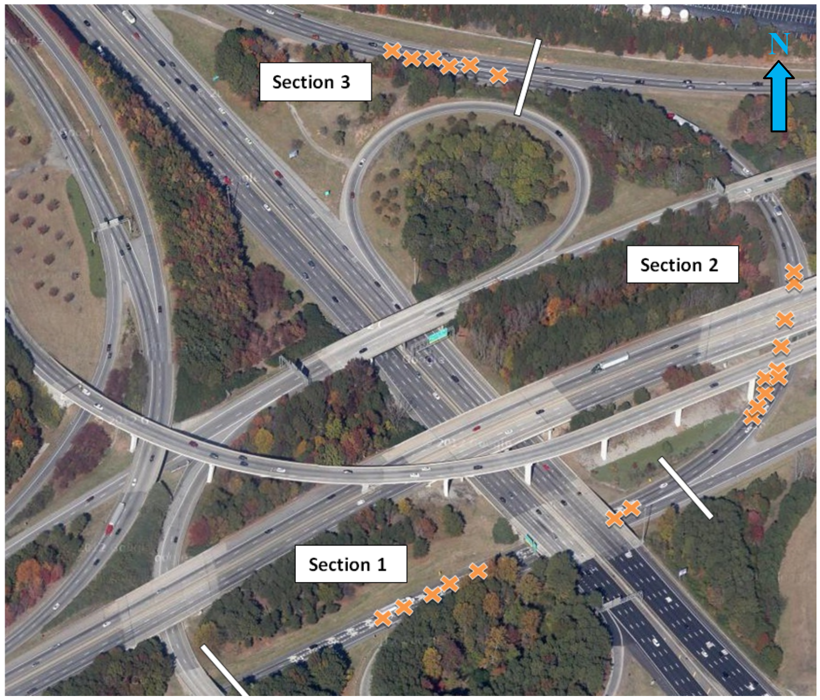


Figure 34: Location of Crashes on I75-I285 Treatment Ramp (Before)

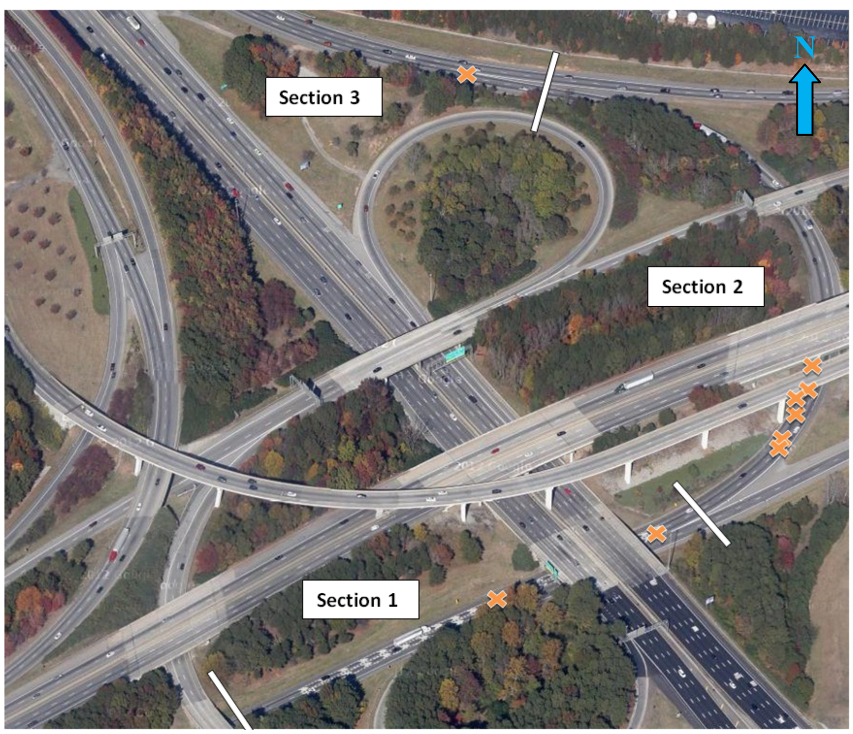


Figure 35: Location of Crashes on I75-I285 Treatment Ramp (After)

4.2.2 Crash Type

Next, the types of crashes were analyzed to see whether there are specific types of crashes that are associated with different ramp sections as was seen in the I75-I85 interchange. The plots of the crashes can be seen on Figure 36 and Figure 37. Table 42 and Table 43 accompany these figures to provide the numerical data.

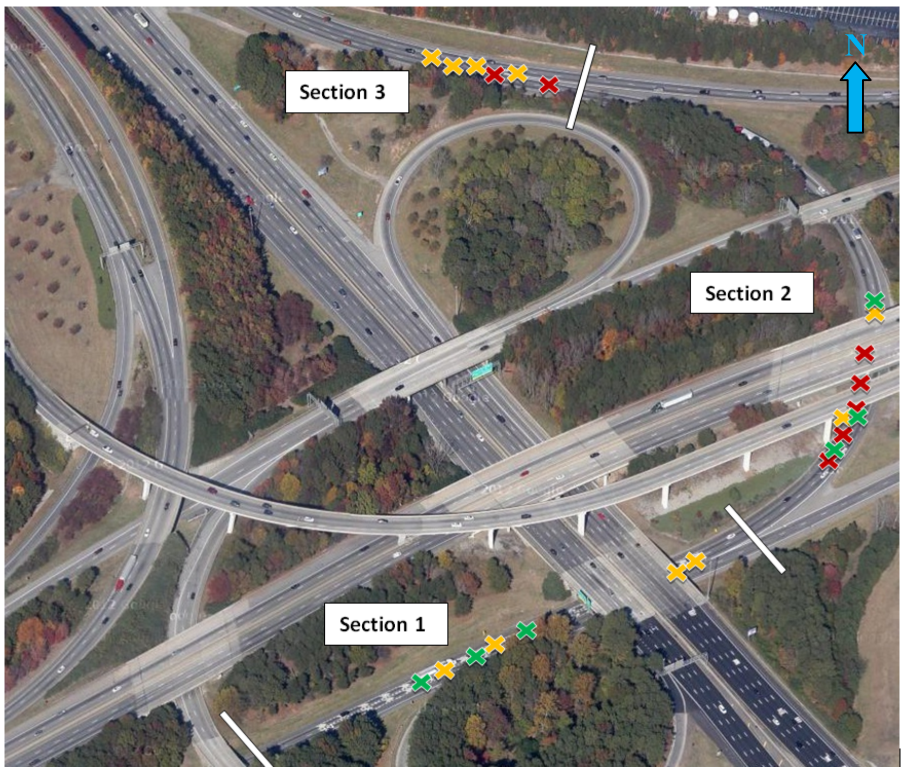


Figure 36: Plot of Crashes by Type on Ramp Sections (I75-I285 Treatment Ramp – Before)

Table 42: Crash Type and Ramp Section (I75-I285 Treatment Ramp - Before)

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Total**
Sec 1	0	0	3	4	0	**7**
Sec 2	0	0	3	2	5	**10**
Sec 3	0	0	0	4	2	**6**
Total	**0**	**0**	**6**	**10**	**7**	**23**

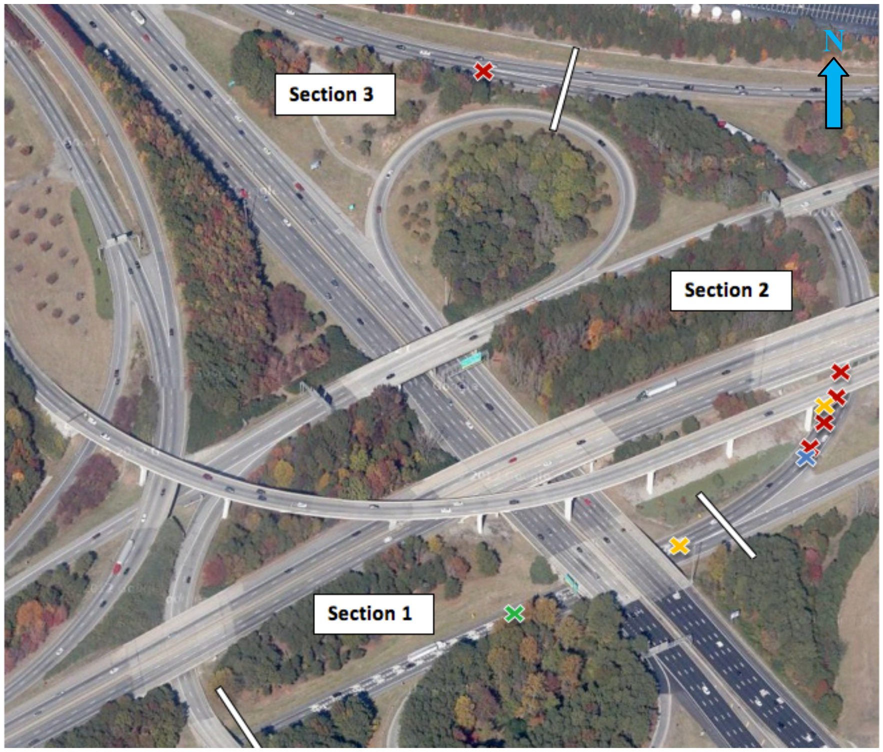


Figure 37: Plot of Crashes by Type on Ramp Sections (I75-I285 Treatment Ramp – After)

Table 43: Crash Type and Ramp Section (I75-I285 Treatment Ramp – After)

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Total**
Sec 1	0	0	1	1	0	**2**
Sec 2	1	0	0	1	4	**6**
Sec 3	0	0	0	0	1	**1**
Total	**1**	**0**	**1**	**2**	**5**	**9**

Single-vehicle crashes again mostly occurred on ramp section 2. However, as shown on Table 42, the dominant crash type in the before period is not single-vehicle crashes but sideswipe crashes. Sideswipe and rear end crashes are found on ramp section 1 as expected due to the slowing down of traffic prior to the curve as well as vehicles swerving into the ramp at the last minute. Sideswipe crashes are also found on ramp section 3, which could be influenced by the merge between this ramp and the ramp to I75N coming from I285W.

The analysis suggests that the chevron markings on this ramp did have a major influence on sideswipe crashes as they were reduced by 8 crashes or 80%, the largest reduction in magnitude from all crash types. Meanwhile, single-vehicle crashes experienced a reduction of 2 crashes (29%) and rear end crashes had a reduction of 5 crashes (83%). The I75-I285 Control Ramp also had reductions in all crash types but at smaller magnitudes and percentages (see Appendix D). Although this suggests that perhaps a portion of the decrease in crashes on the Treatment Ramp is due to some background reductions, the chevron markings did have some influence on the crash reductions.

4.2.3 Day of Week

Next, the days of the week that crashes occurred on were analyzed. Figure 38 and Figure 39 present the distribution of crashes by day of week in the Treatment Ramp for both the before and after periods. The distribution shows that the peak frequency of crashes in the before period occurs on Thursdays and gradually declines from there. This was not seen on the day-of-week distribution of the I75-I85 Treatment Ramp and suggests that perhaps the traffic characteristics at this site are different from that of the I75-I85 Treatment Ramp. However, since the sample size is small, it is difficult to determine whether this peak on Thursdays is an actual trend. In fact, this trend is not seen on the Control Ramp (see Appendix D). However, since the sample size for the Control Ramp is also small, it is also difficult to determine whether that finding is a trend.

There are major crash reductions in the after period on the Treatment Ramp except for Sundays, which experienced an increase of 2 crashes. Again, due to the small sample size, it is difficult to determine whether this increase is an actual trend. Nonetheless, it is important to note that the overall reduction of 14 crashes (61%) on the Treatment Ramp is still consistent with the findings on the I75-I85 Treatment Ramp and is still a significant reduction.

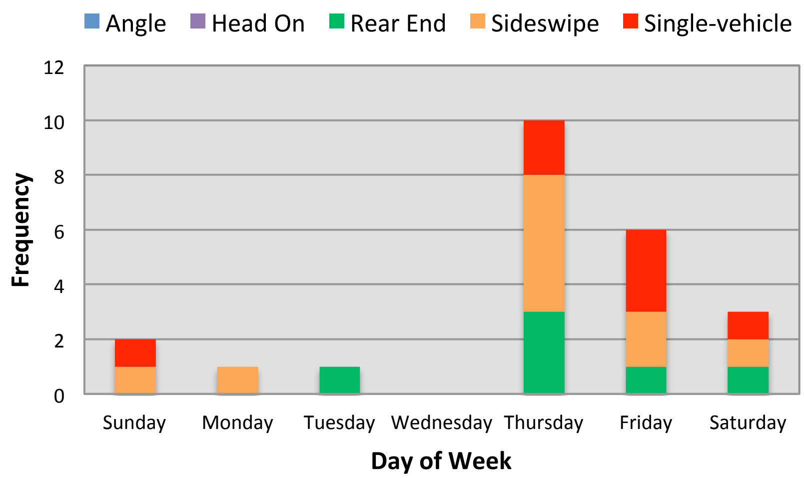


Figure 38: Crash Type and Day of Week (I75-I285 Treatment Ramp - Before)

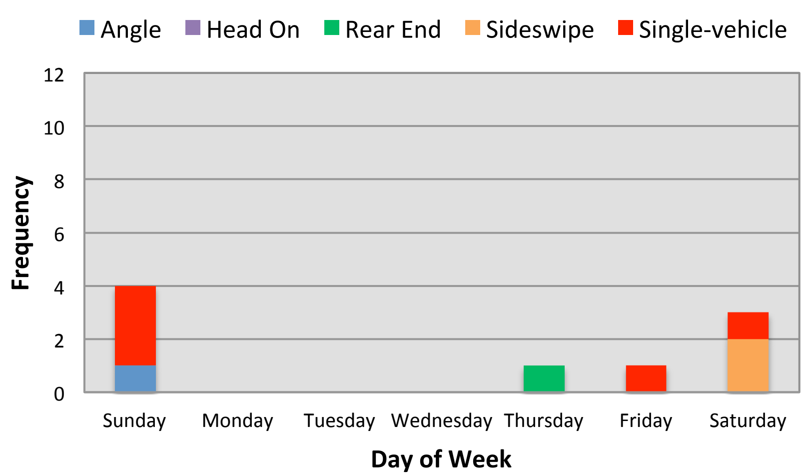


Figure 39: Crash Type and Day of Week (I75-I285 Treatment Ramp - After)

4.2.4 Time of Day

Next, the distribution of crashes across different times of the day was analyzed. The time of day distributions for the Treatment Ramp can be seen on Figure 40 and Figure 41. It appears that the peak frequency of crashes occurs in periods where there is sunlight: 6am-Noon and Noon-6pm, suggesting that they are related with business hours. However, this trend is not seen on the Control Ramp (see Appendix D). In addition, due to the small sample size, this should not be taken as a definite trend.

In the after period, however, crashes that occurred between Midnight and 6 a.m. were completely eliminated while crashes that occurred during other time periods were also greatly reduced. This finding suggests that the chevron markings are having a strong effect on late night and early morning drivers, perhaps drivers coming from social activities. However, since other time periods also experienced reductions, chevron markings do not appear to be more effective during the late night and early morning hours than during other periods.

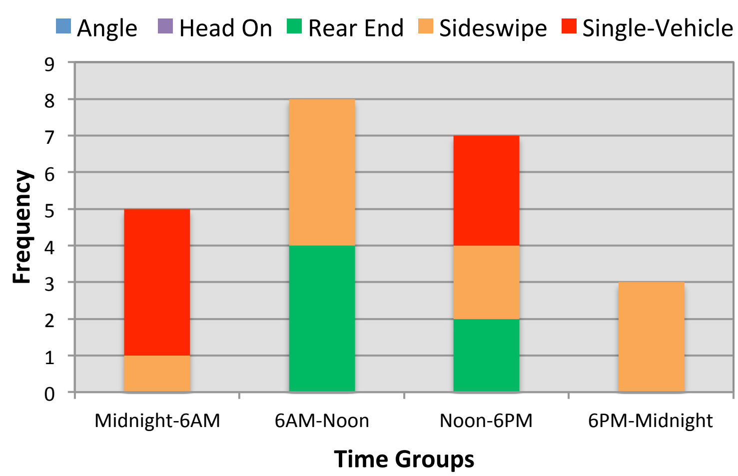


Figure 40: Crash Type and Time of Day (I75-I285 Treatment Ramp - Before)

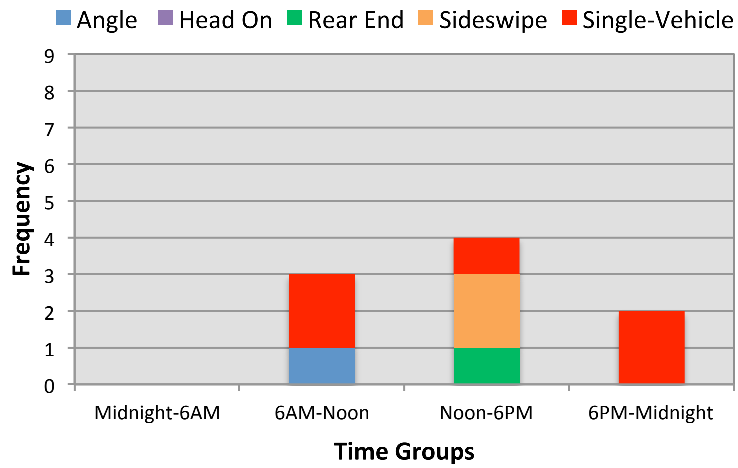


Figure 41: Crash Type and Time of Day (I75-I285 Treatment Ramp - After)

4.2.5 Surface Conditions

An analysis on the effects of wet and dry surface conditions was also performed. Figure 42 shows the surface condition distribution for the Treatment Ramp in the before period and Figure 43 shows the same distribution in the after period. In the before period, the total number of crashes on dry conditions (13 crashes) and wet conditions (10 crashes) are almost equal. Due to the small sample size, it is difficult to judge whether specific crash types were more prevalent during dry or wet conditions. However, it is clear once again that the crashes in wet surface conditions are overrepresented. As previously shown on Table 37, approximately 9% of the total hours in the before period had precipitation and approximately 10% of the total hours in the after period had precipitation [32]. These rates are very low and considering that precipitation does not always result in wet roadway surfaces, the likelihood of having wet roadway surfaces are probably even lower. In contrast, crashes are more prevalent in dry conditions (83%)

than in wet conditions (17%) on the Control Ramp (see Appendix D). However, crashes in wet surface conditions are still slightly overrepresented on this ramp.

In the after period, these crashes were all greatly reduced. Crashes on dry conditions were reduced by 69% to 4 crashes and crashes on wet conditions by 50% to 5 crashes. Meanwhile, the changes in the Control Ramp were very small in sample and no conclusive trends were found (see Appendix D). Therefore, it does not appear that the chevron markings on this ramp are working better in one surface condition than the other; they are influential in reducing crashes in both types of surface condition.

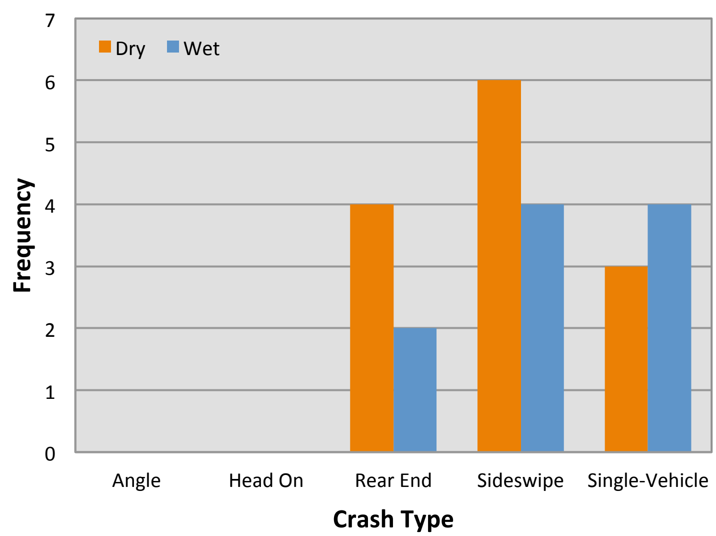


Figure 42: Crash Type and Surface Condition (I75-I285 Treatment Ramp - Before)

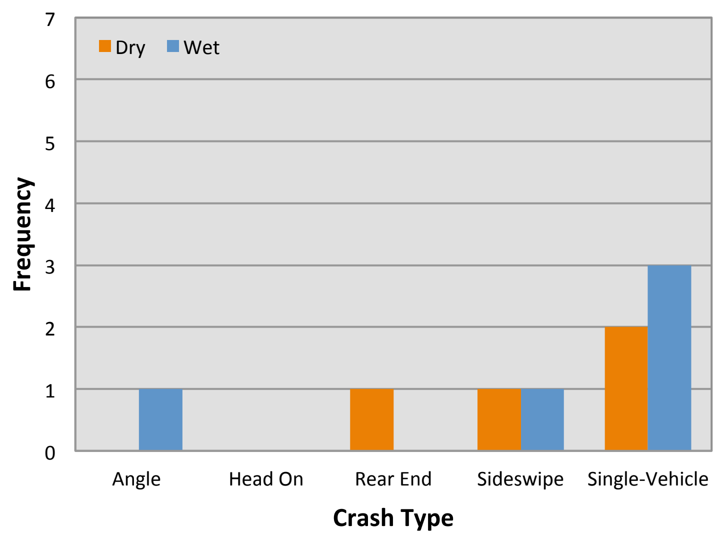


Figure 43: Crash Type and Surface Condition (I75-I285 Treatment Ramp - After)

4.2.6 Vehicle Type

Next, the vehicle composition of the crashes was analyzed. Table 44 and Table 45 present the vehicle compositions of the before and after crashes in the Treatment and Control ramps respectively. In the Treatment Ramp, over 74% of the vehicles in the before period were passenger vehicles, which is a smaller percentage than what was found on the I75-I85 Treatment Ramp. In the Control Ramp, over 66% of the vehicles in the before period were passenger vehicles, which is also smaller than that of the I75-I85 Control Ramp. At this site, there were larger percentages of heavy vehicles in the before period: about 21% on the Treatment Ramp and about 33% on the Control Ramp. This finding shows that the traffic characteristics at this site are likely different from that of the I75-I85 interchange, as previously suggested by the day-of-week analysis. This finding is consistent with the restriction on heavy-vehicles inside the perimeter as shown previously on Figure 27.

On the Treatment Ramp, crashes in all vehicle types were greatly reduced. The same can be said about the crashes in all vehicle types on the Control Ramp though these reductions are somewhat smaller. Nonetheless, it does not appear that the chevron markings are greatly benefitting one vehicle type better than the others. This finding again shows that the chevron markings are beneficial for the entire driving population in these ramps.

Table 44: Composition of Vehicles Involved in Crashes (I75-I285 Treatment Ramp)

Vehicle Type	Before	After	Change	% Change
Passenger Vehicle	29	12	-17	-59%
Heavy Vehicle	8	1	-7	-88%
Other	2	0	-2	-100%
Total	39	13	-26	-67%

Table 45: Composition of Vehicles Involved in Crashes (I75-I285 Control Ramp)

Vehicle Type	Before	After	Change	% Change
Passenger Vehicle	14	10	-4	-29%
Heavy Vehicle	7	3	-4	-57%
Other	0	0	0	0%
Total	21	13	-8	-38%

4.2.7 Age Distribution

The age distribution of drivers in the I75-I285 Treatment Ramp was also analyzed. Figure 44 and Figure 45 present the age distribution of the drivers involved in the crashes on the Treatment Ramp for both the before and after periods. As was seen on the I75-I85 Treatment Ramp, all age groups appear to have experienced a reduction in crashes. Also, drivers in the age group of 16 to 20 years old again appear to not have experienced as large a reduction as other age groups. However, since the numbers are small, it is difficult to retrieve any concrete trends here. In fact, like the age group of 16 to 20 years old, the age group of 51 to 55 years old also appears to not have experienced as large a reduction as other age groups. Similarly, it is also difficult to find any trends from the age distribution of drivers involved in crashes on the Control Ramp (see Appendix D). The important note to be taken here is that the overall number of drivers decreased from 39 in the before period to 13 in the after period, which is a 67% reduction.

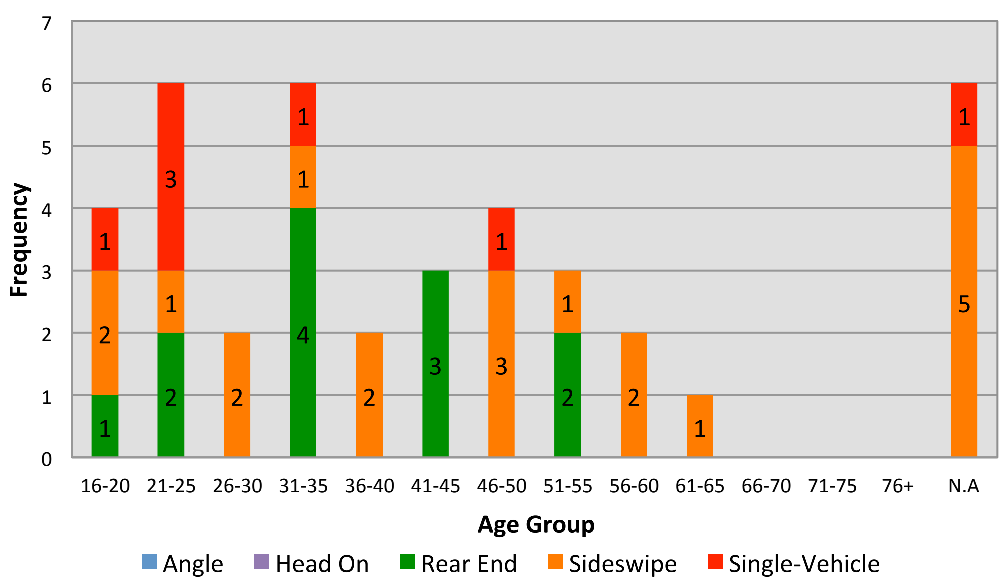


Figure 44: Age Distribution and Crash Type (I75-I285 Treatment Ramp - Before)

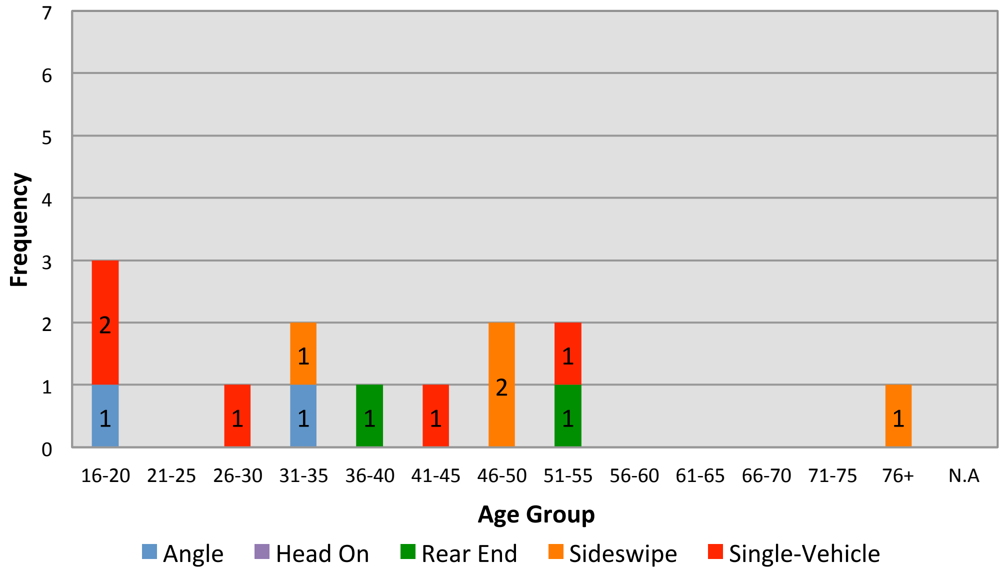


Figure 45: Age Distribution and Crash Type (I75-I285 Treatment Ramp - After)

4.2.8 Gender Distribution

The gender distribution of drivers in the I75-I285 Treatment Ramp was also analyzed. Figure 46 and Figure 47 present the gender distribution of the drivers involved in crashes on the Treatment Ramp for both the before and after periods. As previously mentioned, between 2006 and 2009, virtually 50% of licensed drivers were male while the other 50% were female [5]. It appears that male drivers are again overrepresented in the sample. In the before period, 72% of the drivers were male. In the after period, 69% of the drivers were male. This overrepresentation is also seen on the Control Ramp (see Appendix D). Nonetheless, it appears as though both male and female drivers have benefitted almost equally from the chevron markings: female drivers experienced a reduction of 64% while male drivers 68%. Therefore, the chevron markings do not appear to be affecting one gender group better than the other.

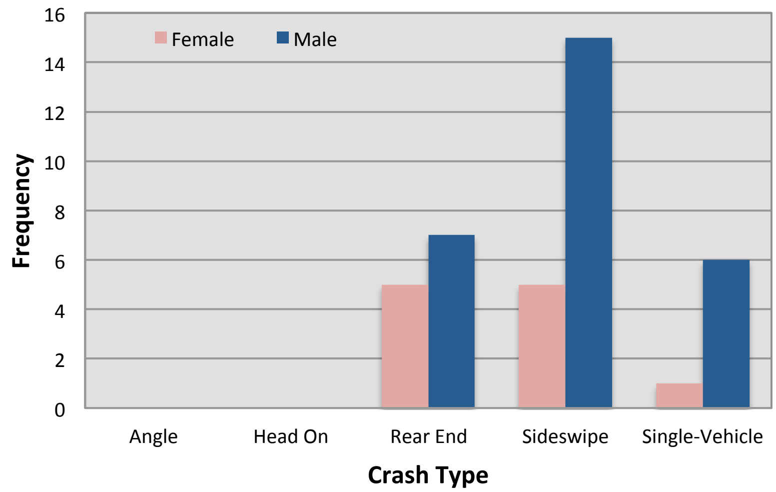


Figure 46: Gender and Crash Type (I75-I285 Treatment Ramp - Before)

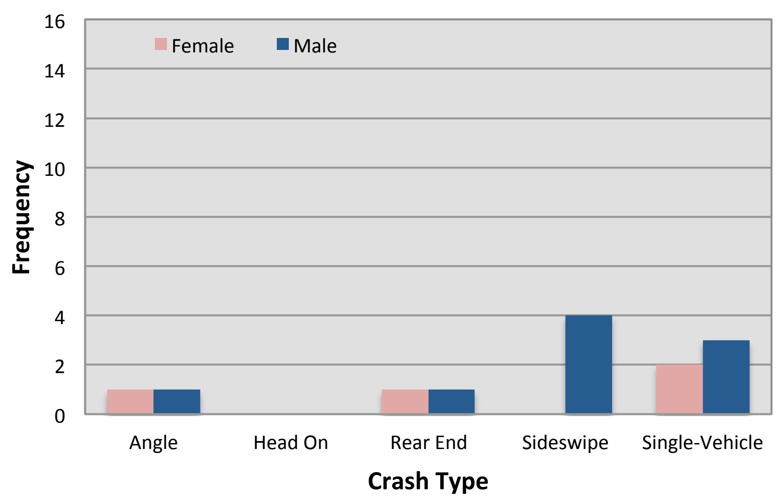


Figure 47: Gender and Crash Type (I75-I285 Treatment Ramp - After)

4.2.9 Driver Familiarity

For the analysis of driver familiarity, the county of residence of drivers was again used as a surrogate. Unfamiliarity with the area, in this case, is defined as having a county of residence outside of the 13-county Atlanta metro region defined in a study by

Nelson et al. [33]. Figure 48 and Figure 49 present the distribution of driver familiarity in terms of different crash types on the Treatment Ramp for the before and after periods.

The analysis shows that in the before period, 64% of drivers involved in the crashes (25 out of 39 drivers) were from counties inside of the 13-county area. Similarly in the after period, 62% of drivers involved in the crashes (8 out of 13 drivers) were from counties inside of the 13-county area. This finding suggests that drivers familiar with the area are still very much vulnerable to the sharp curve. However, it is important to note that drivers that live outside of the 13-county area are overrepresented in both periods: 18% of drivers in the before period and 38% of drivers in the after period. Meanwhile, Nelson et al. [33] reported that only 10.5% of their license plate data were from counties outside of the 13-county area. Therefore, this overrepresentation suggests that unfamiliar drivers are more vulnerable to the sharp curve than familiar drivers.

In the after period, large reductions were observed for both groups: drivers familiar with the area experienced a reduction of 68% while drivers unfamiliar with the area experienced a reduction of 29%. The driver familiarity distribution for the Control Ramp can be seen in Appendix D. However, it is difficult to state from the analysis on the Control Ramp if there are significant reductions that can be attributed to a general reduction in the background traffic characteristics at this site. Hence, there is not sufficient evidence to show that the chevron markings are addressing one type of driver better than the other.

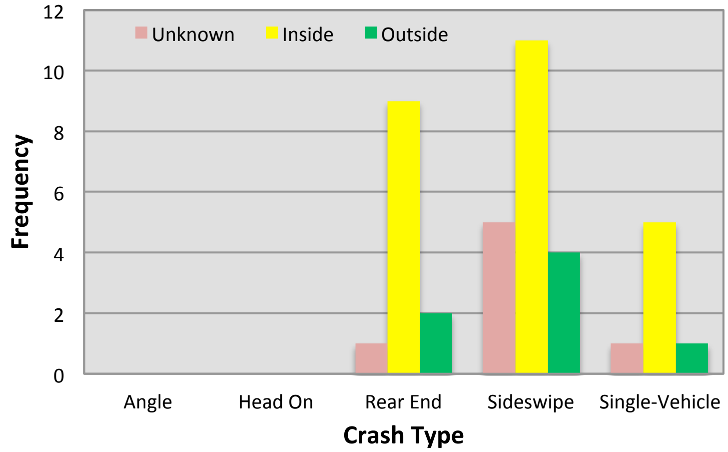


Figure 48: County of Residence and Crash Type (I75-I285 Treatment Ramp - Before)

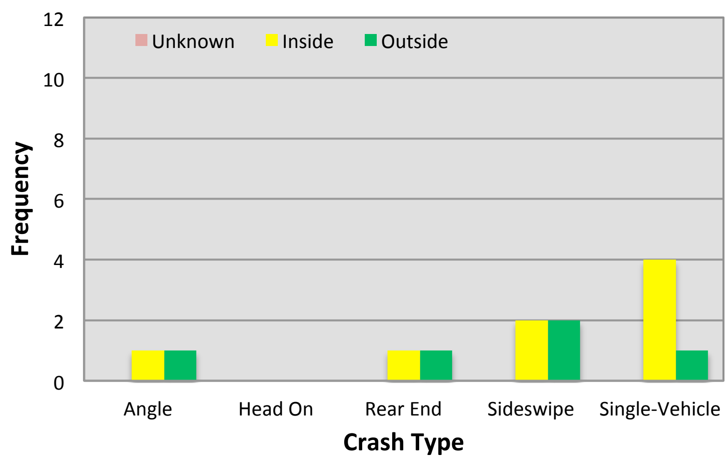


Figure 49: County of Residence and Crash Type (I75-I285 Treatment Ramp - After)

4.2.10 Explanatory Factors

The results of the I75-I285 police report analysis is presented in this section. The purpose of using the explanatory factors is to find support for the trends that are seen from the attributes that have been analyzed. Table 46 shows the explanatory factors found for the Treatment Ramp crashes. In the before period, the top 3 factors are loss of control, improper lane change and close following. These 3 factors support the finding that single-vehicle crashes are not necessarily the most prevalent on this ramp but other crash types like sideswipes and rear ends are also prevalent. Since losing control and close following are still mentioned in almost a third of the crashes, the mechanism of vehicles coming in at speeds that are excessive for the curve is also valid on this ramp. However, the high percentage of improper lane change suggests that vehicles are also having issues with maintaining their lanes. As section 4.2.2 showed, there are sideswipe crashes in all sections of the ramp. Sideswipe crashes on ramp section 2 suggest the same crash mechanism as those that are coming in at excessive speeds and losing control. On the other hand, sideswipe crashes on ramp section 1 suggests that vehicles are merging onto the ramp at the last second perhaps due to lack of clear understanding of where they are in the interchange. Also, sideswipe crashes on ramp section 3 suggest that vehicles are having issues merging with the traffic coming from I285 WB. Hence, a possible explanation for crashes on this interchange could be due to the confusion from the many ramps and movements. However, due to the small sample size, significantly more data is needed to confirm the explanations. In addition, the small sample size also makes it difficult to determine whether the chevron markings had an influence on these crashes.

Table 46: I75-I285 Treatment Ramp Explanatory Factors

Police Report Explanatory Factor	Before		After		Change
	#	%	#	%	
Alcohol	1	4.4	1	11.1	0
Avoidance maneuver	3	13.0	2	22.2	-1
Close following	6	26.1	0	0.0	-6
Deliberate risk-taking	2	8.7	0	0.0	-2
Excess speed (limit & conditions)	4	17.4	2	22.2	-2
Failure to maintain lane	4	17.4	6	66.7	+2
Failure to merge	0	0.0	0	0.0	0
Fell asleep	0	0.0	0	0.0	0
Forced off road/lane by other vehicle	1	4.4	2	22.2	+1
Improper lane change	8	34.8	2	22.2	-6
Inattentive/distracted	1	4.4	0	0.0	-1
Load problems (heavy-vehicle)	0	0.0	0	0.0	0
Lost control of vehicle	7	30.4	7	77.8	0
Misjudged sharpness of curve	0	0.0	0	0.0	0
Panic/nervous	0	0.0	0	0.0	0
Slippery roads	0	0.0	2	22.2	+2
Vehicle defects	1	4.4	2	22.2	+1
Unknown	1	4.4	0	0.0	-1

Table 47 present the explanatory factors found for the Control Ramp crashes. Since the sample size is even smaller here than on the Treatment Ramp, it is more difficult to obtain meaningful trends from these results. Nonetheless, these findings show the type of factors that contribute to the crashes on these ramps.

Table 47: I75-I285 Control Ramp Explanatory Factors

Police Report Explanatory Factor	Before		After		Change
	#	%	#	%	
Alcohol	0	0.0	0	0.0	0
Avoidance maneuver	0	0.0	0	0.0	0
Close following	3	25.0	2	25.0	-1
Deliberate risk-taking	0	0.0	0	0.0	0
Excess speed (limit & conditions)	1	8.3	3	37.5	+2
Failure to maintain lane	2	16.7	1	12.5	-1
Failure to merge	4	33.3	1	0.0	-3
Fell asleep	1	8.3	0	0.0	-1
Forced off road/lane by other vehicle	0	0.0	0	0.0	0
Improper lane change	1	8.3	4	50.0	+3
Inattentive/distracted	1	8.3	0	0.0	-1
Load problems (heavy-vehicle)	0	0.0	0	0.0	0
Lost control of vehicle	4	33.3	3	37.5	-1
Misjudged sharpness of curve	0	0.0	0	0.0	0
Panic/nervous	0	0.0	0	0.0	0
Slippery roads	0	0.0	1	12.5	+1
Vehicle defects	0	0.0	0	0.0	0
Unknown	0	0.0	0	0.0	0

CHAPTER 5: CONCLUSIONS, LIMITATIONS & FURTHER RESEARCH

5.1 Conclusions

The purpose of this research was to evaluate the safety performance of chevron markings on the two freeway-to-freeway ramps in Atlanta, Georgia, in order to quantify their potential significant safety benefits and to develop an understanding of the crash types that are being addressed. Prior to analysis, the crash reduction rates were verified at each treatment and control ramps. Next, an in-depth before and after crash analysis was conducted using crash data and police reports. In an effort to find underlying crash patterns, several crash attributes were analyzed and crash descriptions from the available police reports were analyzed as well. The following sections provide a brief discussion of the results presented in this thesis.

5.1.1 I75-I85 Interchange

Verification of the crash reduction rates at the I75-I85 interchange showed that the Treatment Ramp experienced a 73% crash reduction while the Control Ramp experienced a 1% crash reduction. This suggests that the chevron markings made a significant contribution to the crash reduction. The crash attribute analysis showed that although there are specific groups of crashes that benefitted more from the chevron markings than others, such as single-vehicle crashes and ramp section 2 crashes, the entire population appeared to have benefitted from the treatment.

Additionally, the crash description analysis showed that the Treatment Ramp crashes in the before period were largely caused by excessive speeds, leading to a loss of control or a failure to maintain lane. This is consistent with the finding that the primary crash type on this interchange is single-vehicle crash followed by sideswipe/angle crash. The crash descriptions also offered several potential reasons for such maneuvers, including alcohol-use, fatigue, inattention/distraction, panic, vehicle defects, and misjudgment of curve sharpness. In the after period, the results show that the chevron markings reduced the occurrences of all these explanatory factors.

The results of the analysis of the I75-I85 ramps suggest that the chevron markings can be used as a safety treatment in a variety of ways. From the reductions that are seen for all crash types and for all explanatory factors, it does not appear that the chevron markings are only effective on certain types of crashes. On the contrary, it appears that all types of crashes have benefitted from the treatment.

5.1.2 I75-I285 Interchange

Verification of the crash reduction rates at the I75-I285 interchange showed that the Treatment Ramp experienced a 61% crash reduction while the Control Ramp experienced a 33% crash reduction. This suggests that the benefits of the chevron markings significantly exceed any background reductions that can be determined from the trends on the Control Ramp. However, due to the small sample size of crashes for both the Treatment and Control ramps at this site, the analysis of the crash attributes as well as crash descriptions were inconclusive. Nonetheless, the chevron markings at this site are still likely having an impact in enhancing the safety of the facility.

5.2 Limitations

One limitation to this study is the unavailability of a number of police reports. This limitation did not allow for a complete crash data analysis. Instead, a portion of the crashes with missing police reports were proportionally selected and included in the analysis, and their crash attributes were generated as well. However, since this adjustment was done systematically based on the proportions of the original sample, it is likely that many of the results are transferable.

Another limitation of this research is that there may be errors in how the research team obtained the appropriate crash records for the desired locations from the database. This limitation exists partly because clear descriptions of how the databases were created and clear definitions of each variable in the database were not available. Thus, the methodology of locating the appropriate crash records in the database was simply based on explorations performed by the research team. Different explorations of the databases were also conducted prior to the study to ensure that these possibilities can be minimized, and this is reflected in the methodology. Additionally, this limitation is partly due also to the nature of crash data. Although clear instructions and definitions for how to use the databases would help minimize this limitation, there are always going to be human error in the initial database creation process.

5.3 Further Research

One of the goals of this research was to be able to use the results to develop an understanding of potential site characteristics that would indicate that chevron markings might be an effective safety treatment. Since the chevron markings have been found to benefit all crashes on the treatment ramps, it is difficult to use this conclusion to understand what are the potential site characteristics more conducive to chevron implementation. Therefore, it is crucial that researchers and traffic engineers understand the potential uses of chevron markings even more.

Ultimately, more chevron markings need to be used in order that its potential uses are better understood. Although this seems to be a reactive approach to understanding the treatment, it is the only method that would guarantee primary data. Potential sites should be selected based on what is currently understood about the treatment from the several studies that have been done across the country. For example, previous studies have agreed that the chevron markings should be used in freeway connector ramps where the speeds required to traverse the facility are often much lower than the upstream and downstream free flow speed. The combination of horizontal and vertical curvature at freeway-to-freeway connectors often limits sight distance, which complicates speed selection with drivers not being able to view the curve in its entirety. Such locations should be appropriate for the chevron markings. Crash frequencies for these sites would also need to be analyzed to determine whether in fact there is a speeding issue that leads to crashes.

Alternatively, studies could be done to better understand the behaviors of the drivers traversing such facilities. Driving simulators could be used for this purpose. A roadway that resembles one that has been proven to benefit from the chevron markings could be designed and various human factors could be studied, including inattention, distraction, fatigue, and alcohol-use. The findings of such studies could be used to identify locations where similar human errors have been found numerous times to lead to crashes.

This thesis should serve as another stepping-stone toward understanding the potential uses of chevron markings. Much more research and knowledge will be required to achieve full understanding of this treatment. Hopefully in the near future, locations can be selected with certainty that chevron markings will enhance their safety.

APPENDIX A: CRASH ATTRIBUTE GENERATION

The generation of crash attributes for the additional crashes on the I75-I85 Treatment and Control ramps involves several steps. The variables ramp section and crash type will be used as an example to portray how these attributes are generated for the additional crashes. First, the before data for crash type and ramp section is obtained and tabulated (see Table 48).

Table 48: Before Data for Crash Type and Ramp Section

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Grand Total**
1	1	0	4	3	1	9
2	6	0	3	7	32	48
3	2	1	0	2	0	5
Grand Total	9	1	7	12	33	62

Next, for each category, the percentage of total is calculated by dividing every value on Table 48 by the total number of crashes (i.e. 62). The results of this can be seen on Table 49.

Table 49: Percentage of Crashes Relative to the Total

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Grand Total**
1	0.016	0.000	0.065	0.048	0.016	0.145
2	0.097	0.000	0.048	0.113	0.516	0.774
3	0.032	0.016	0.000	0.032	0.000	0.081
Grand Total	0.145	0.016	0.113	0.194	0.532	1.000

Then, using the percentages that have been calculated, the additional crash attributes can be estimated. This example is from the I75-I85 Treatment Ramp data, and as calculated in section 3.1.6.1, the additional number of crashes for this ramp is 11 crashes. This total number of additional crashes is then multiplied by each of the proportions on Table 49. The results of this step can be seen on Table 50.

Table 50: Additional Crashes

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Grand Total**
1	0	0	1	1	0	2
2	1	0	0	1	6	8
3	1	0	0	0	0	1
Grand Total	2	0	1	2	6	11

Table 50 presents the crash type and ramp section for the additional 11 crashes on this ramp. Now that these crashes have their attributes, they can be added into the before data to arrive at the adjusted-before data. The adjusted-before data can be seen on Table 51.

Table 51: Adjusted Data for Crash Type and Ramp Section

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Grand Total**
1	1	0	5	4	1	11
2	7	0	3	8	38	56
3	3	1	0	2	0	6
Grand Total	11	1	8	14	39	73

These steps are repeated for generating all the other desired crash attributes. To ensure that this is done properly, the number of additional crashes per crash type is kept constant throughout the generation of the other crash attributes. Thus, there are always 2 additional angle crashes, 0 additional head on crashes, 1 additional rear end crash, 2 additional sideswipe crashes, and 6 additional single-vehicle crashes. The other attributes are generated while keeping these values constant.

A similar procedure can be conducted for vehicle-level attributes (this example uses a crash-level attribute). And similarly, the number of additional vehicles per crash type is only generated once in the beginning and kept constant for all other vehicle-level attributes.

APPENDIX B: ADDITIONAL GRAPHS FOR I75-I85 TREATMENT RAMP

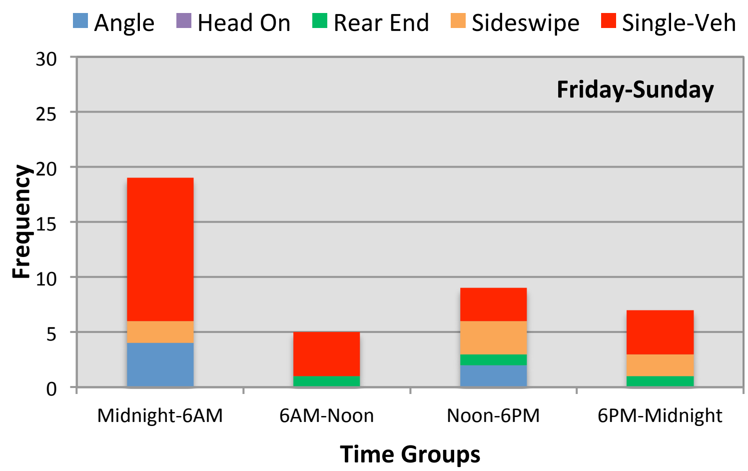


Figure 50: Weekend Crash Type and Time of Day (I75-I85 Treatment Ramp - Before)

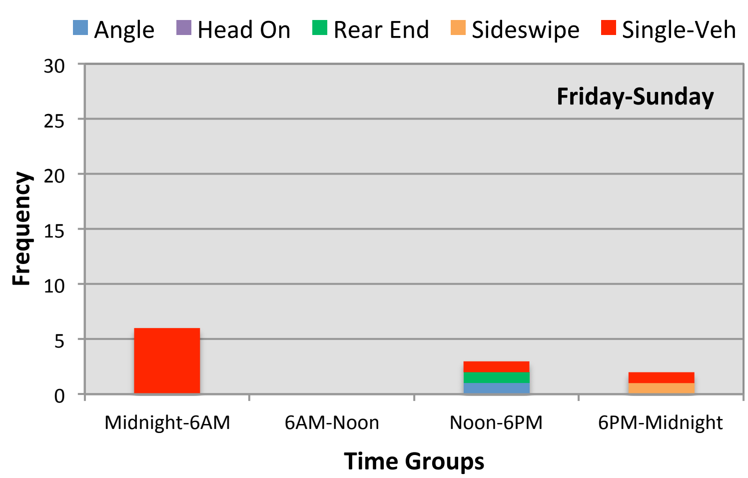


Figure 51: Weekend Crash Type and Time of Day (I75-I85 Treatment Ramp - After)

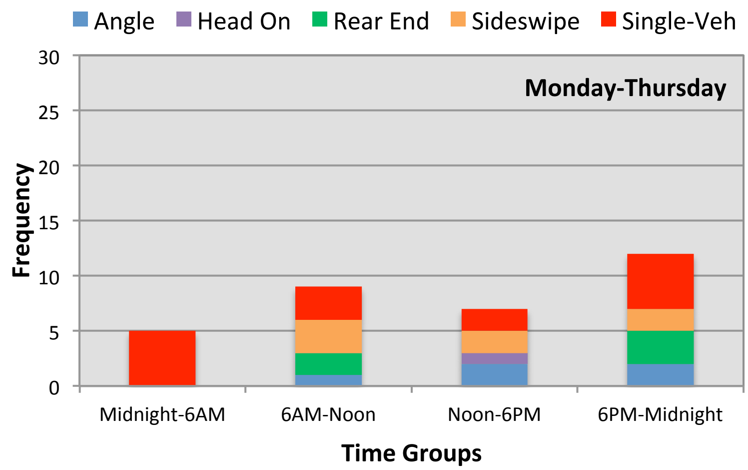


Figure 52: Weekday Crash Type and Time of Day (I75-I85 Treatment Ramp - Before)

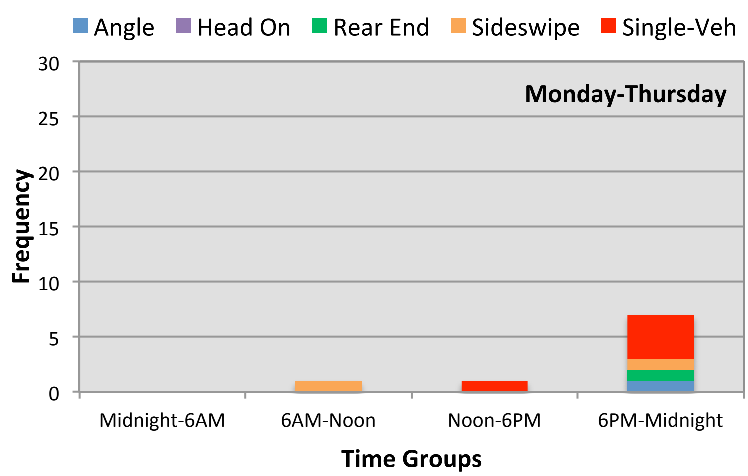


Figure 53: Weekday Crash Type and Time of Day (I75-I85 Treatment Ramp - After)

APPENDIX C: FIGURES FOR I75-I85 CONTROL RAMP

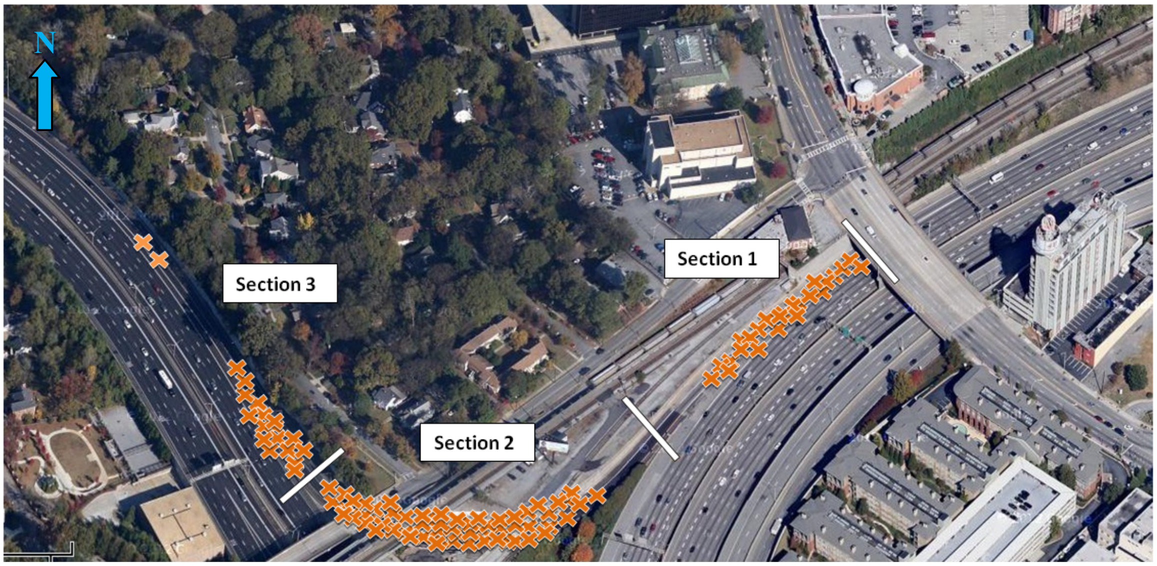


Figure 54: Location of Crashes on I75-I85 Control Ramp (Adjusted-Before)

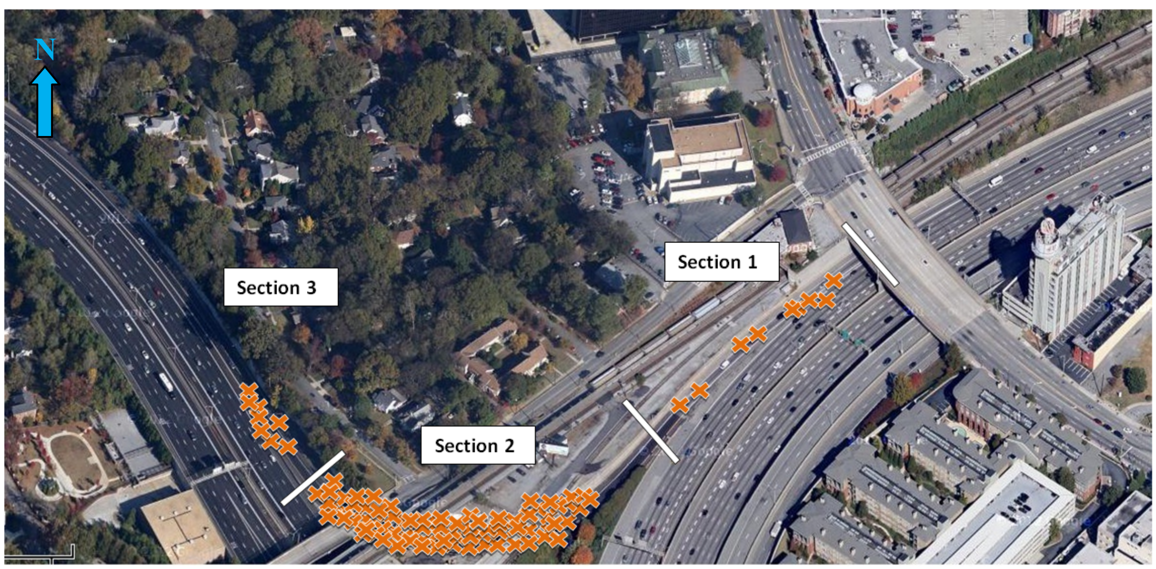


Figure 55: Location of Crashes on I75-I85 Control Ramp (After)

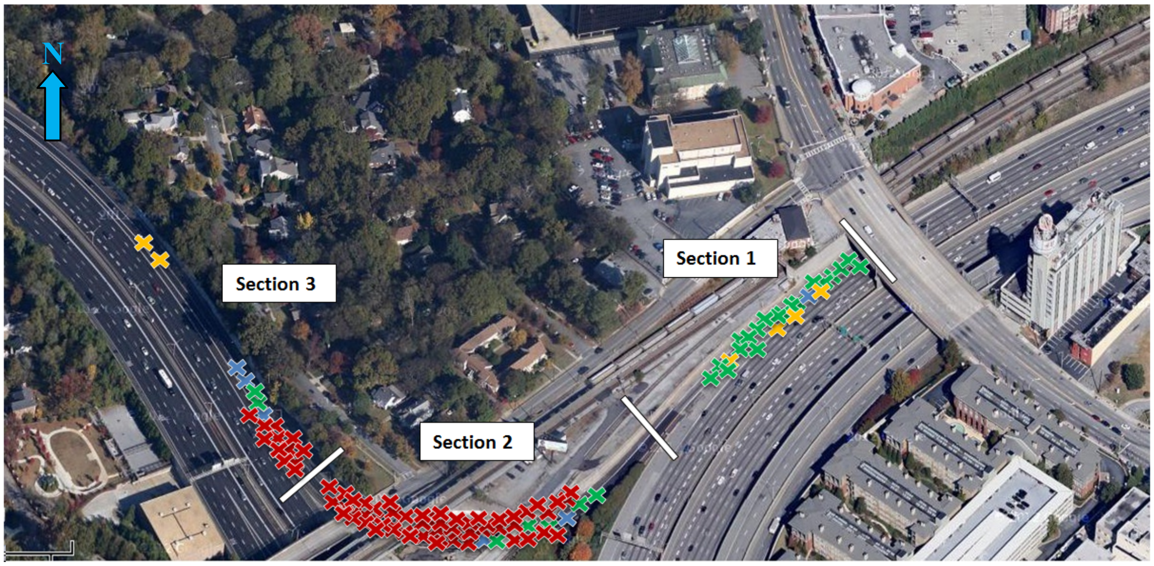


Figure 56: Plot of Crashes by Type (I75-I85 Control Ramp - Adjusted-Before)

Table 52: Crash Type and Ramp Section (I75-I85 Control Ramp - Adjusted-Before)

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Total**
Sec 1	1	0	19	4	0	**24**
Sec 2	2	0	5	0	56	**63**
Sec 3	3	0	2	2	12	**19**
Total	**6**	**0**	**26**	**6**	**68**	**106**

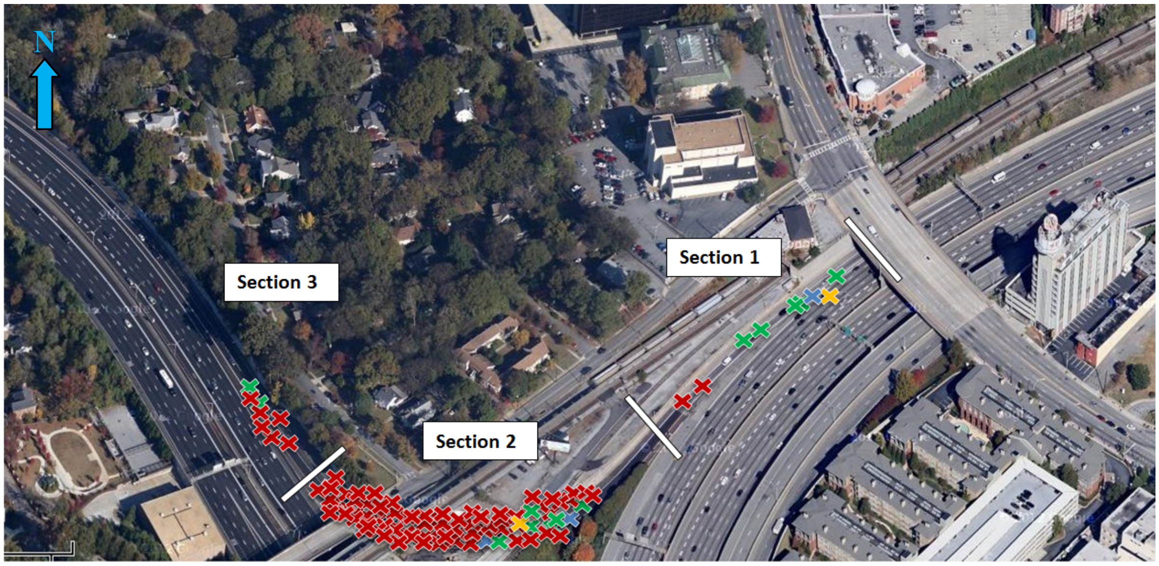


Figure 57: Plot of Crashes by Type (I75-I85 Control Ramp - After)

Table 53: Crash Type and Ramp Section (I75-I85 Control Ramp - After)

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Total**
Sec 1	1	0	5	1	2	**9**
Sec 2	3	0	6	1	78	**88**
Sec 3	0	0	2	0	6	**8**
Total	**4**	**0**	**13**	**2**	**86**	**105**

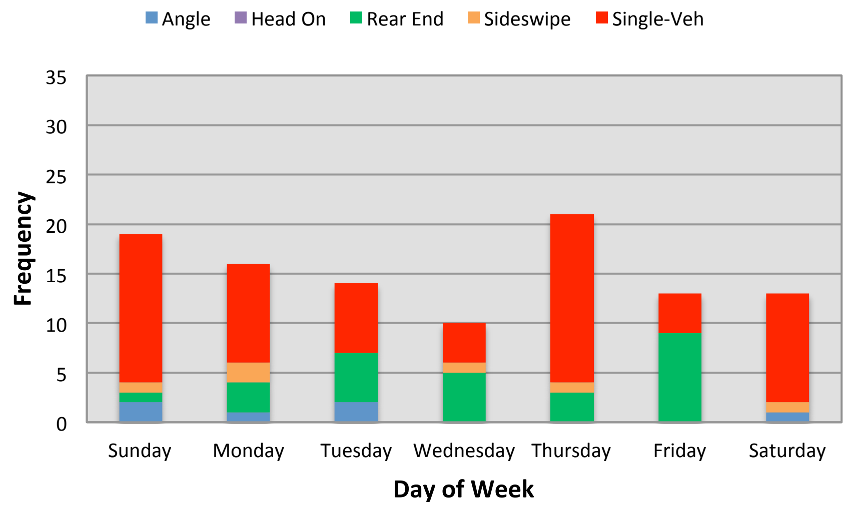


Figure 58: Crash Type and Day of Week (I75-I85 Control Ramp - Adjusted-Before)

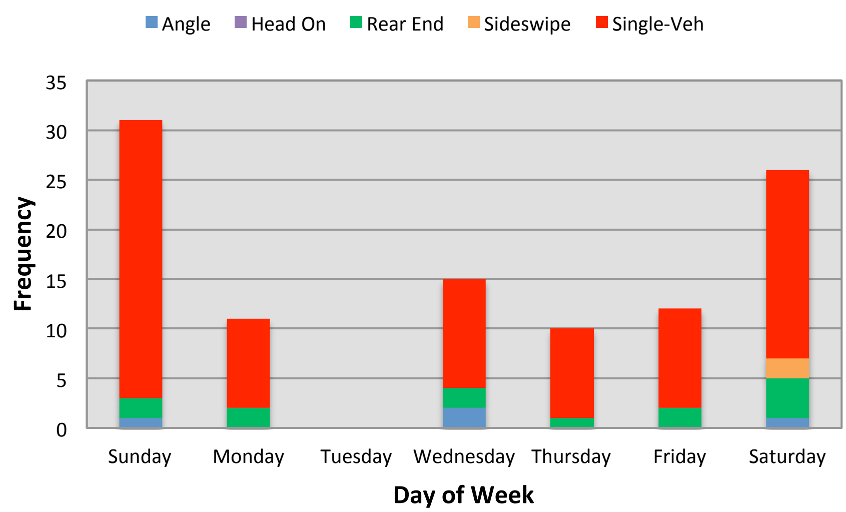


Figure 59: Crash Type and Day of Week (I75-I85 Control Ramp - After)

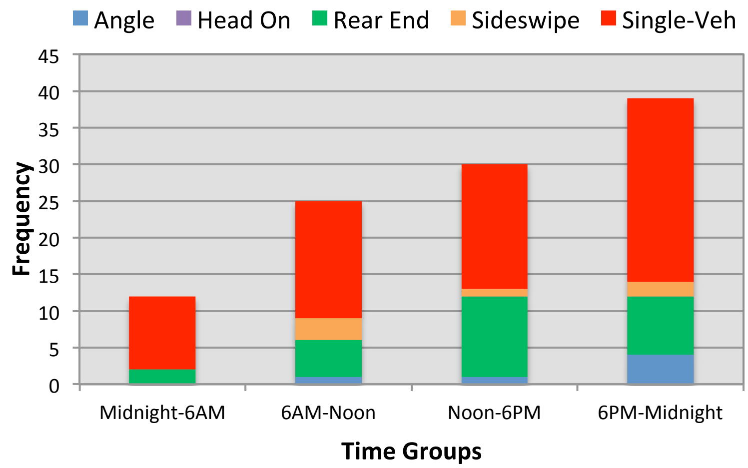


Figure 60: Crash Type and Time of Day (I75-I85 Control Group - Adjusted-Before)

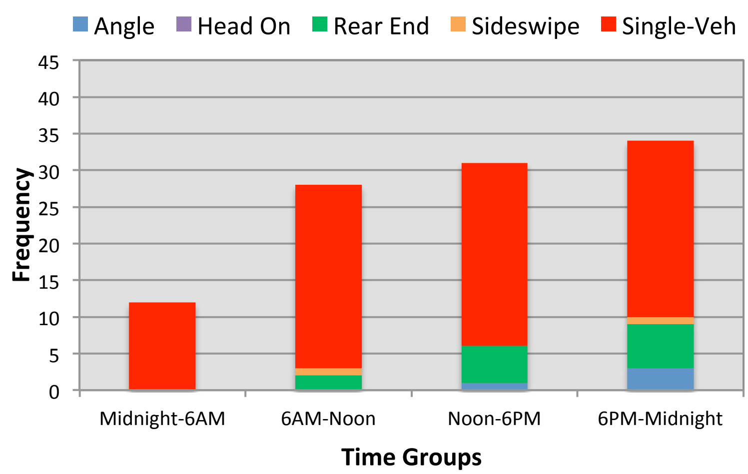


Figure 61: Crash Type and Time of Day (I75-I85 Control Group - After)

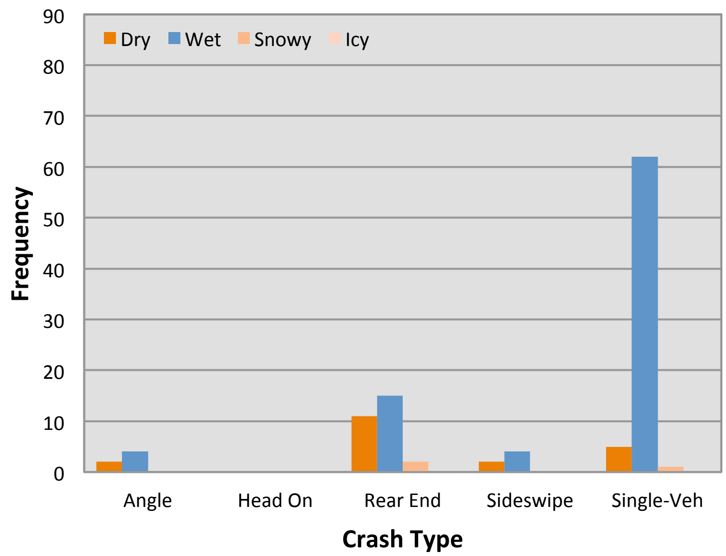


Figure 62: Crash Type and Surface Condition (I75-I85 Control Ramp - Adjusted-Before)

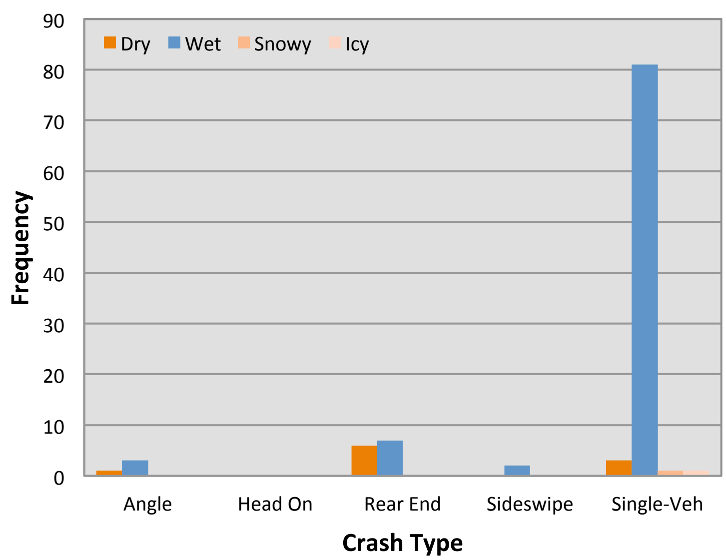


Figure 63: Crash Type and Surface Condition (I75-I85 Control Ramp - After)

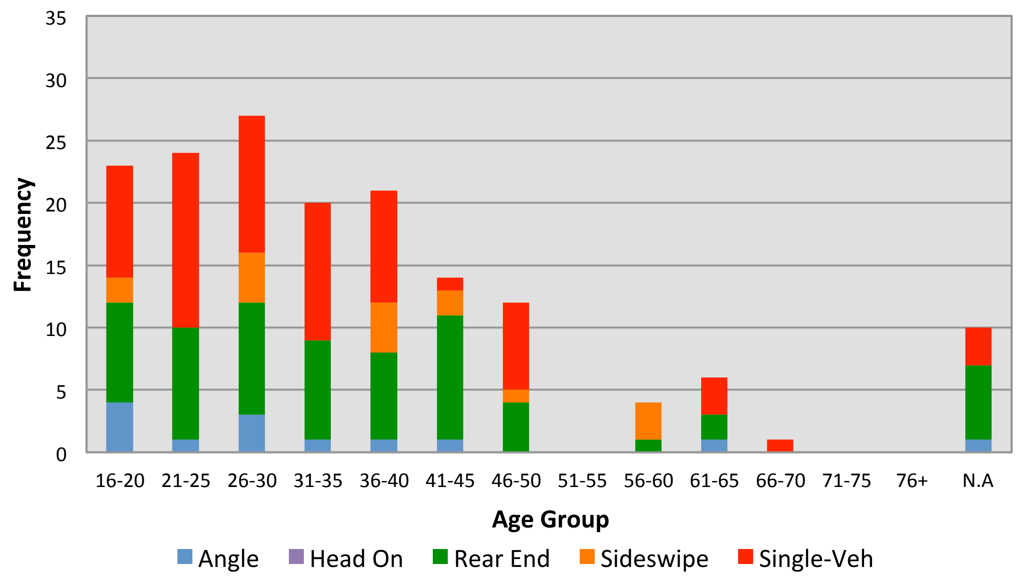


Figure 64: Age Distribution and Crash Type (I75-I85 Control Ramp - Adjusted-Before)

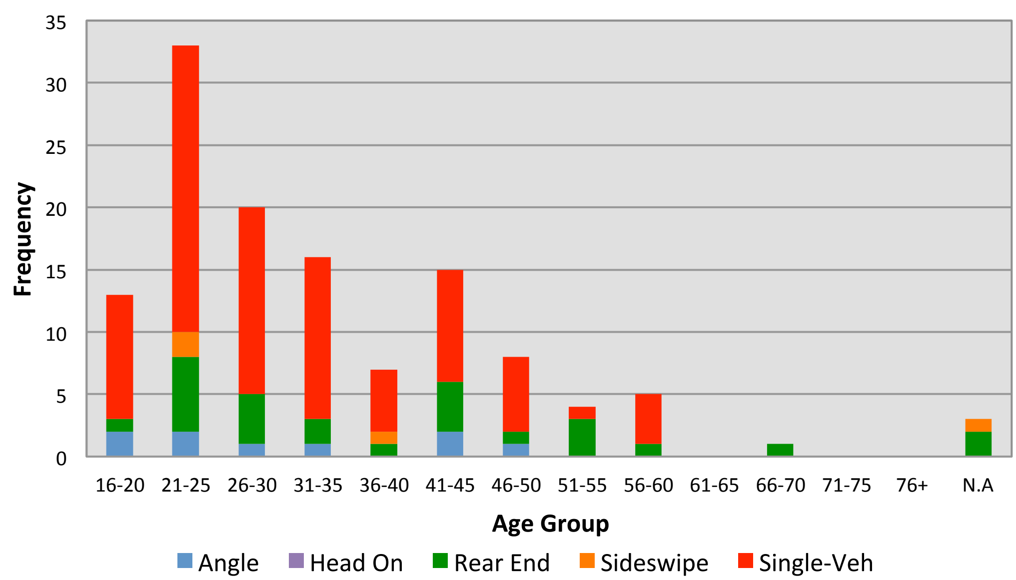


Figure 65: Age Distribution and Crash Type (I75-I85 Control Ramp - After)

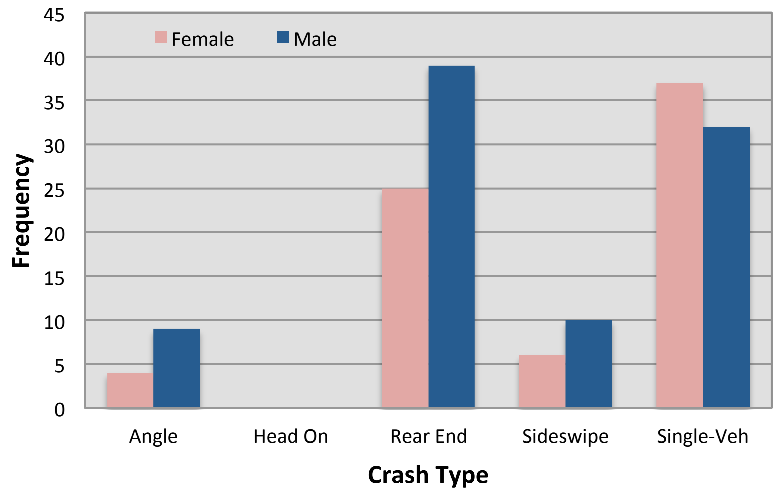


Figure 66: Gender and Crash Type (I75-I85 Control Ramp - Adjusted-Before)

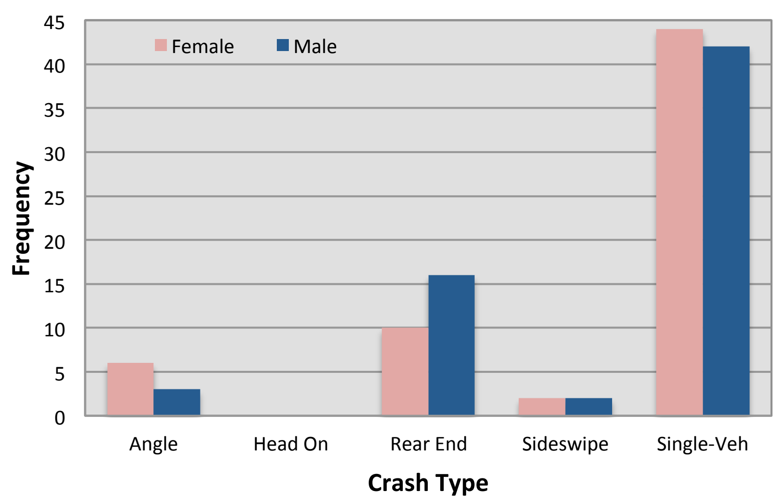


Figure 67: Gender and Crash Type (I75-I85 Control Ramp - After)

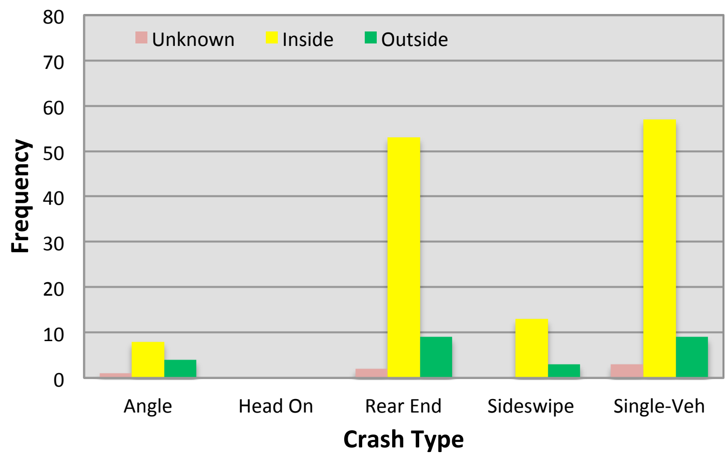


Figure 68: County of Residence and Crash Type (I75-I85 Control Ramp - Adjusted-Before)

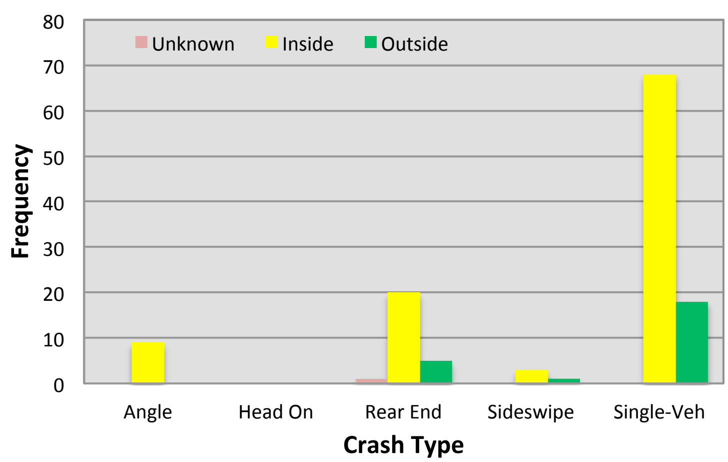


Figure 69: County of Residence and Crash Type (I75-I85 Control Ramp - After)

APPENDIX D: FIGURES FOR I75-I285 CONTROL RAMP

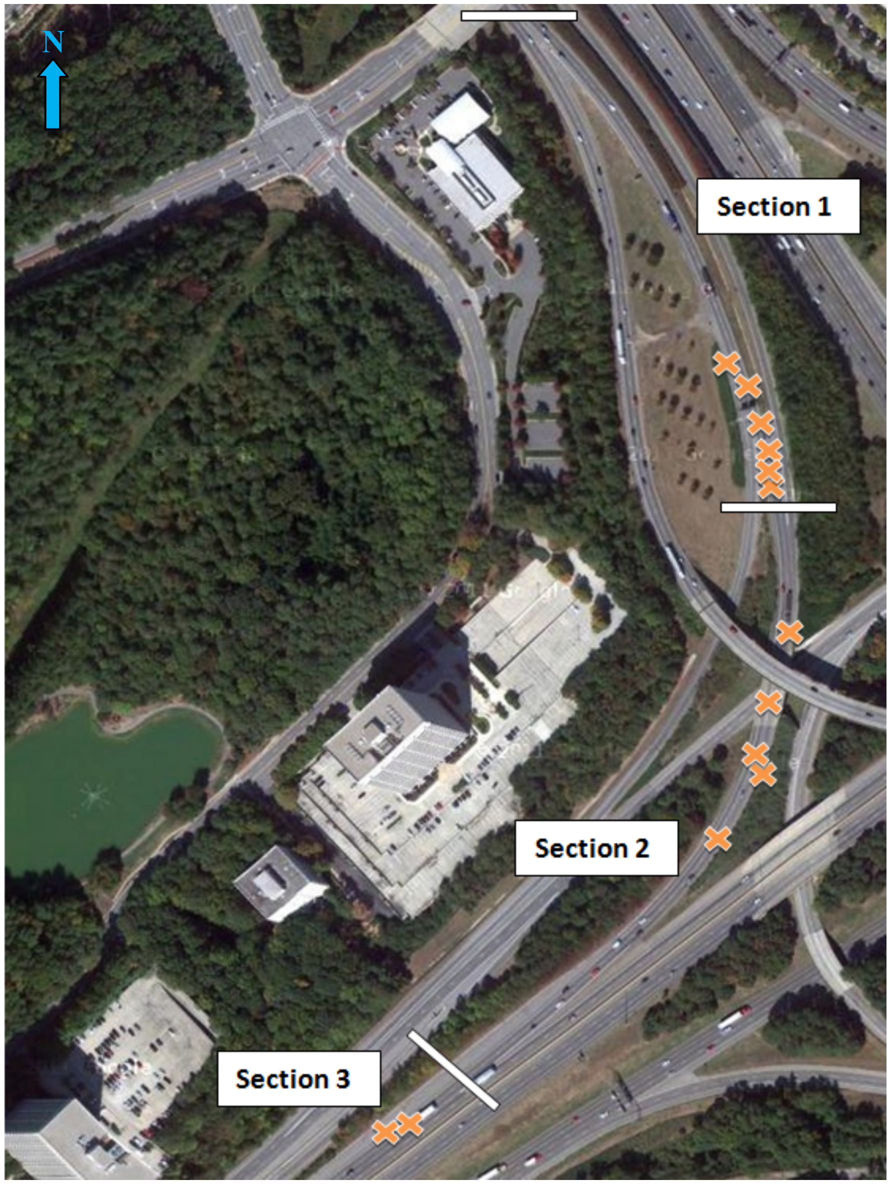


Figure 70: Location of Crashes on I75-I285 Control Ramp (Before)

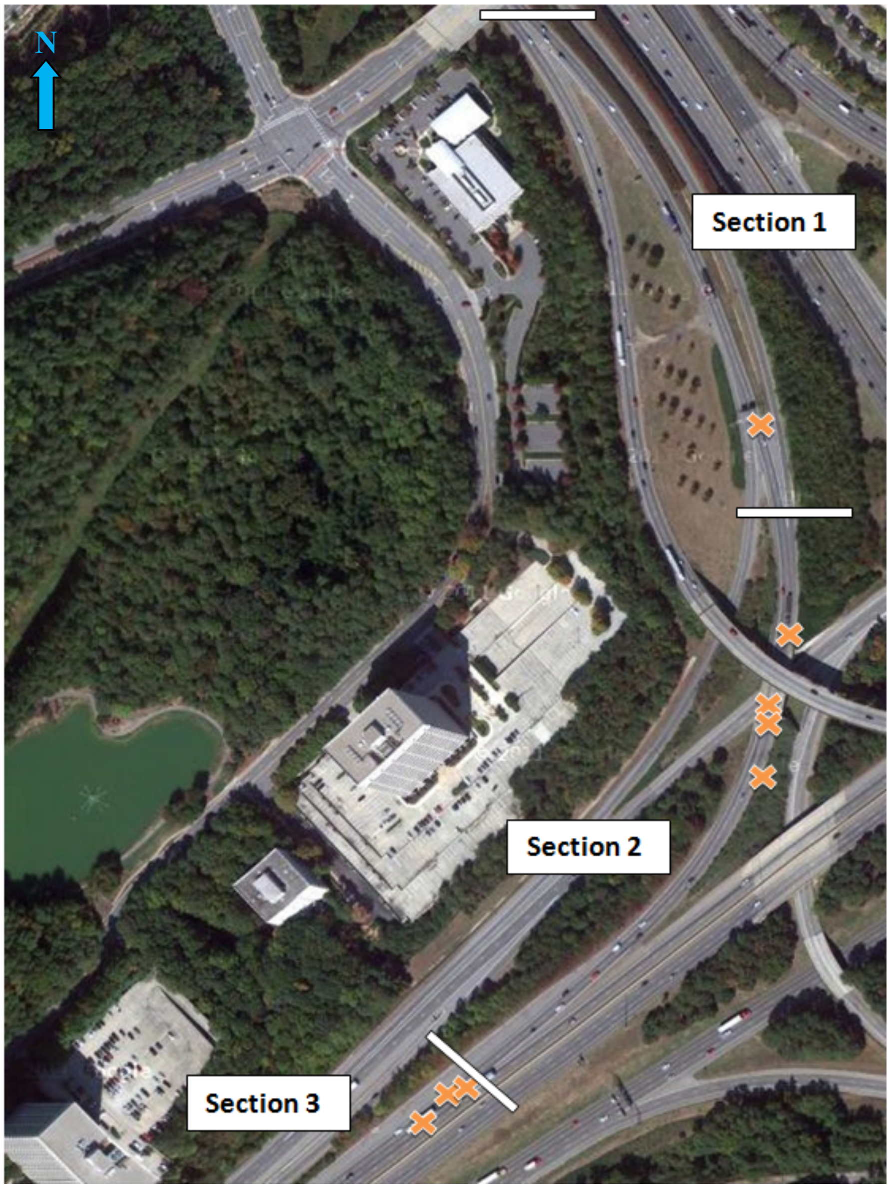


Figure 71: Location of Crashes on I75-I285 Control Ramp (After)

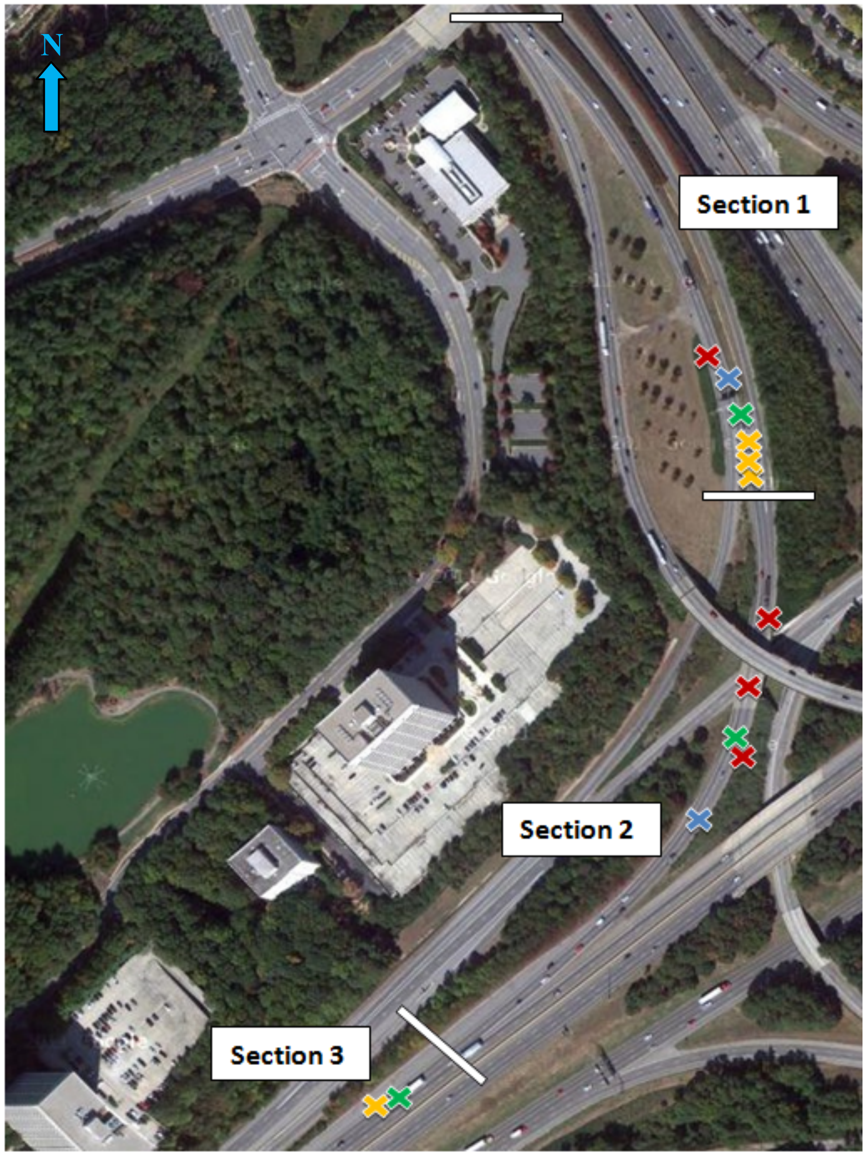


Figure 72: Plot of Crashes by Type (I75-I285 Control Ramp - Before)

Table 54: Crash Type and Ramp Section (I75-I285 Control Ramp - Before)

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Total**
Sec 1	1	0	1	3	1	**6**
Sec 2	1	0	1	0	3	**5**
Sec 3	0	0	1	1	0	**2**
Total	**2**	**0**	**3**	**4**	**4**	**13**

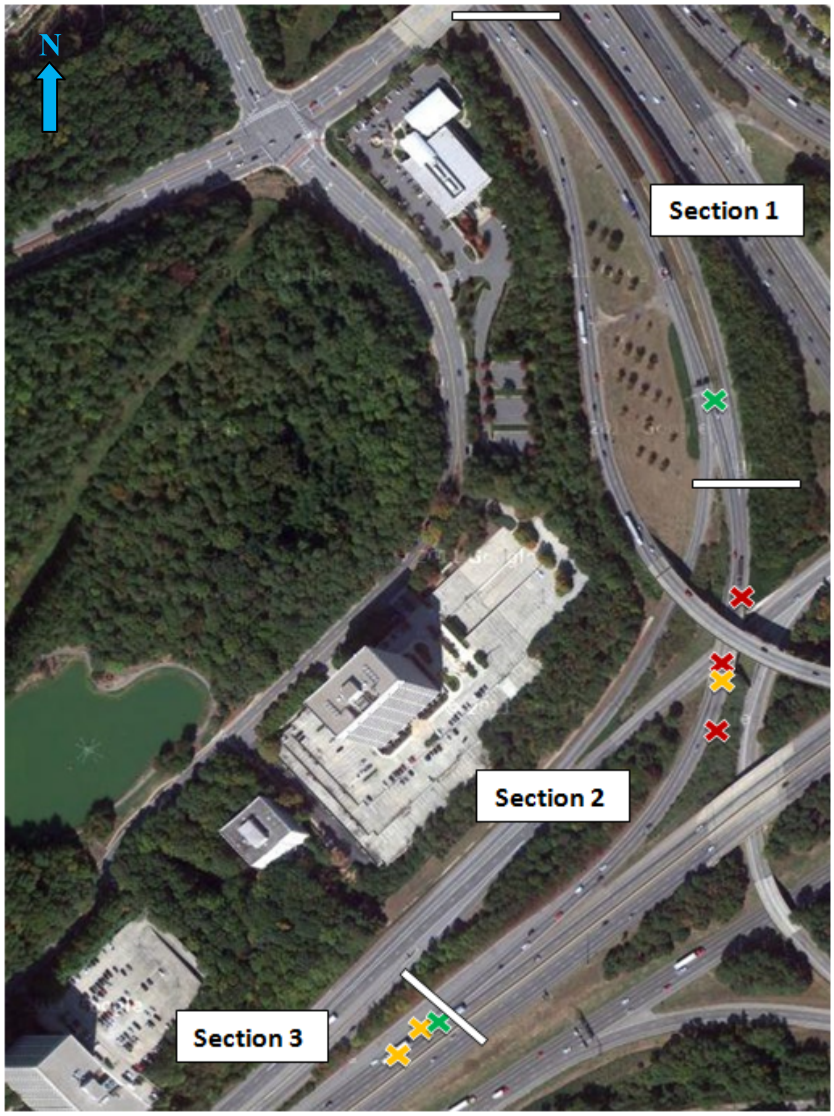


Figure 73: Plot of Crashes by Type (I75-I285 Control Ramp - After)

Table 55: Crash Type and Ramp Section (I75-I285 Control Ramp - After)

	Crash Type					
Ramp Section	**Angle**	**Head On**	**Rear End**	**Sideswipe**	**Single-Vehicle**	**Total**
Sec 1	0	0	1	0	0	**1**
Sec 2	0	0	0	1	3	**4**
Sec 3	0	0	1	2	0	**3**
Total	**0**	**0**	**2**	**3**	**3**	**8**

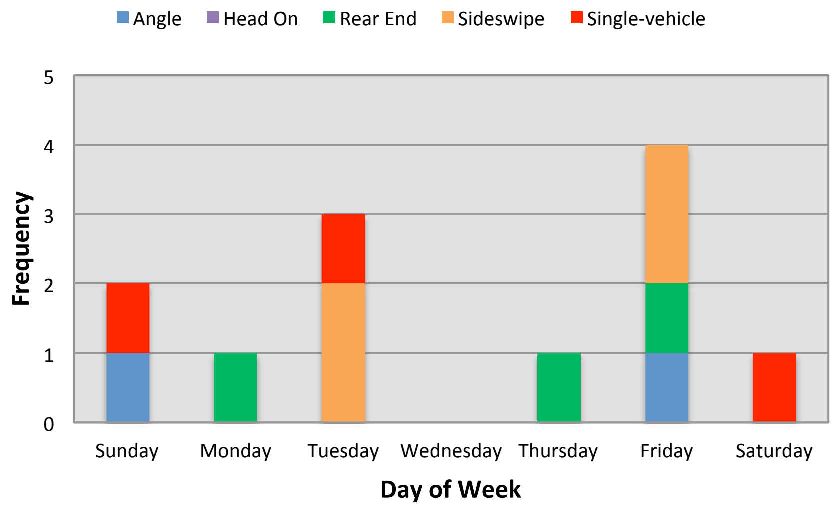


Figure 74: Crash Type and Day of Week (I75-I285 Control Ramp - Before)

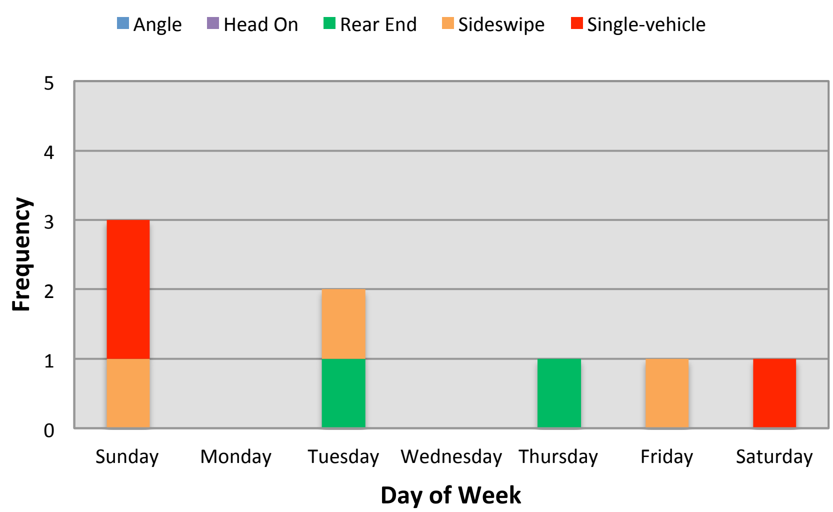


Figure 75: Crash Type and Day of Week (I75-I285 Control Ramp - After)

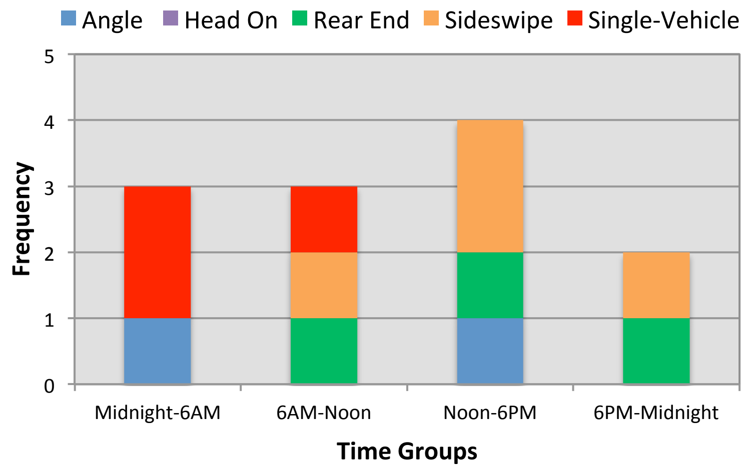


Figure 76: Crash Type and Time of Day (I75-I285 Control Ramp - Before)

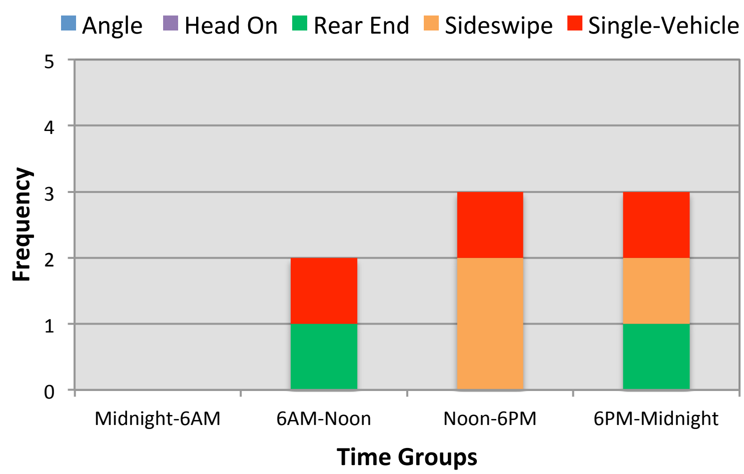


Figure 77: Crash Type and Time of Day (I75-I285 Control Ramp - After)

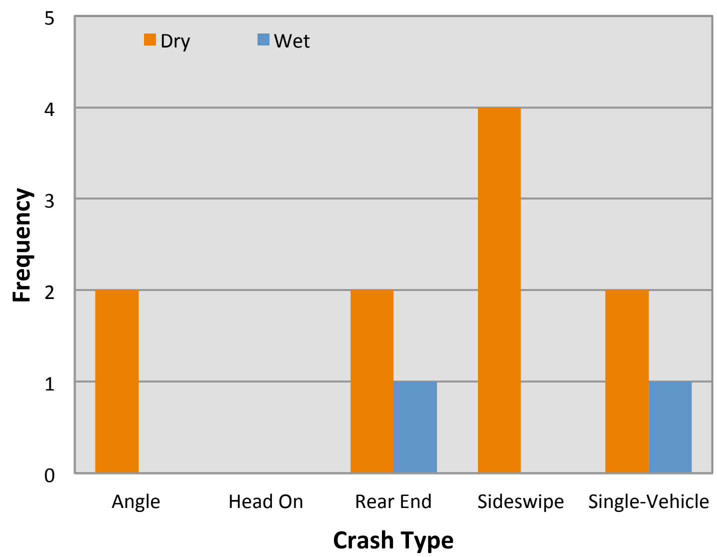


Figure 78: Crash Type and Surface Condition (I75-I285 Control Ramp - Before)

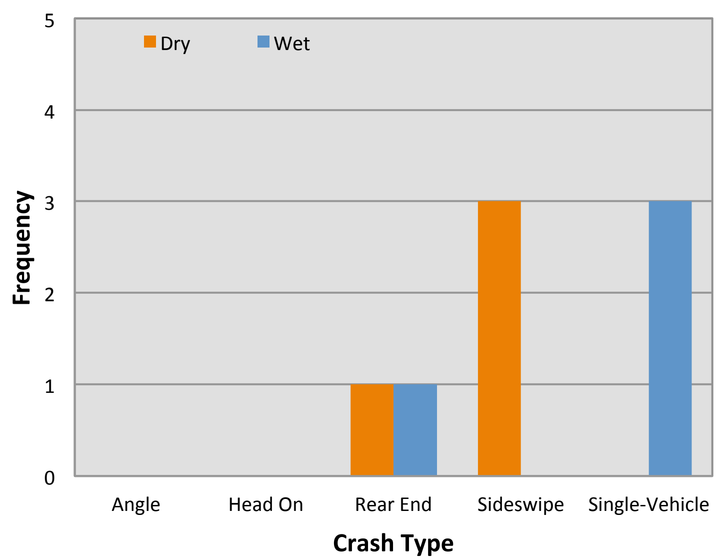


Figure 79: Crash Type and Surface Condition (I75-I285 Control Ramp - After)

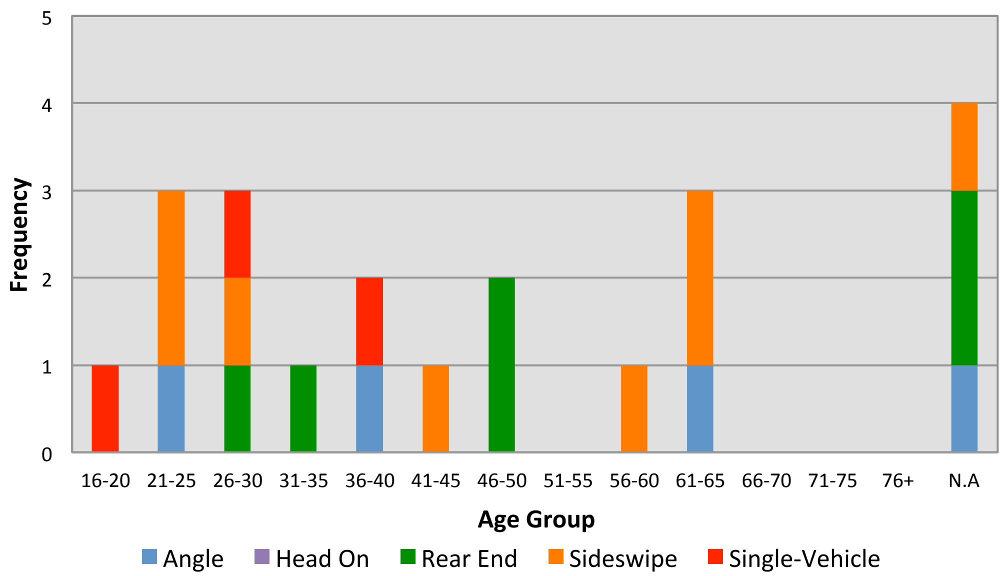


Figure 80: Age Distribution and Crash Type (I75-I285 Control Ramp - Before)

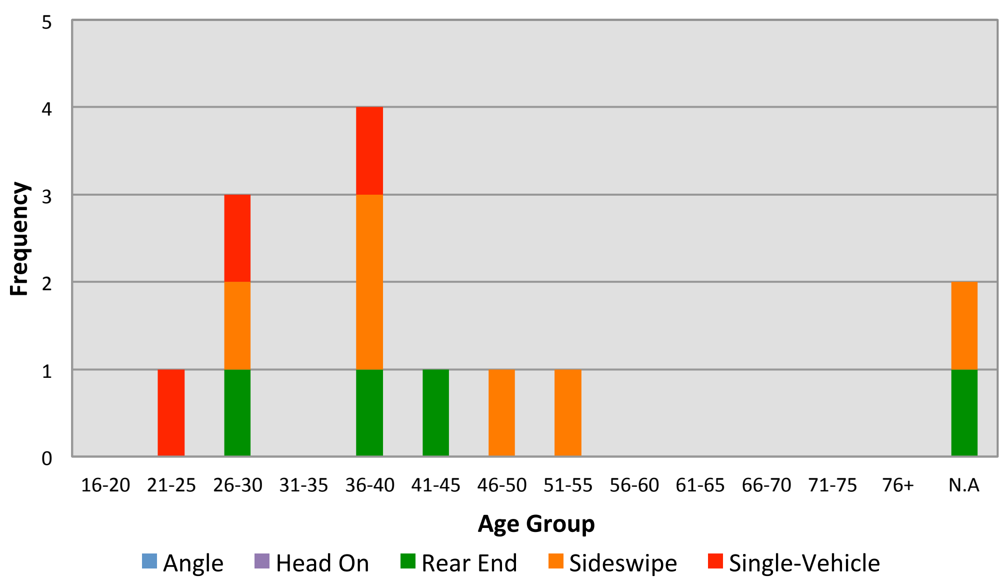


Figure 81: Age Distribution and Crash Type (I75-I285 Control Ramp - After)

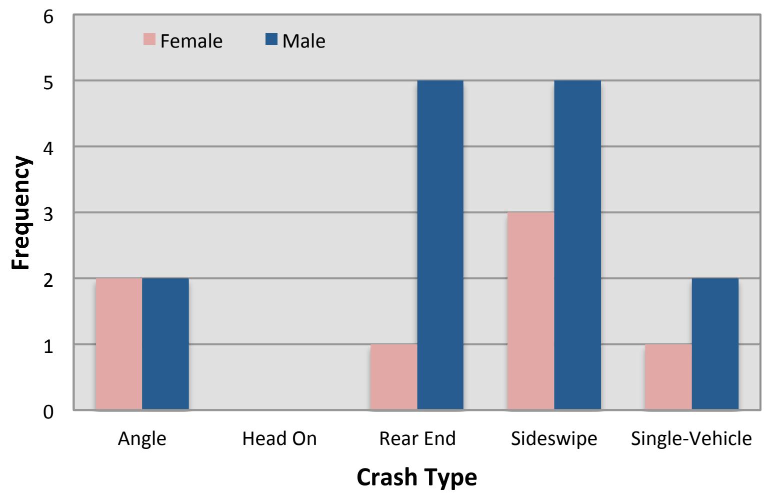


Figure 82: Gender and Crash Type (I75-I285 Control Ramp - Before)

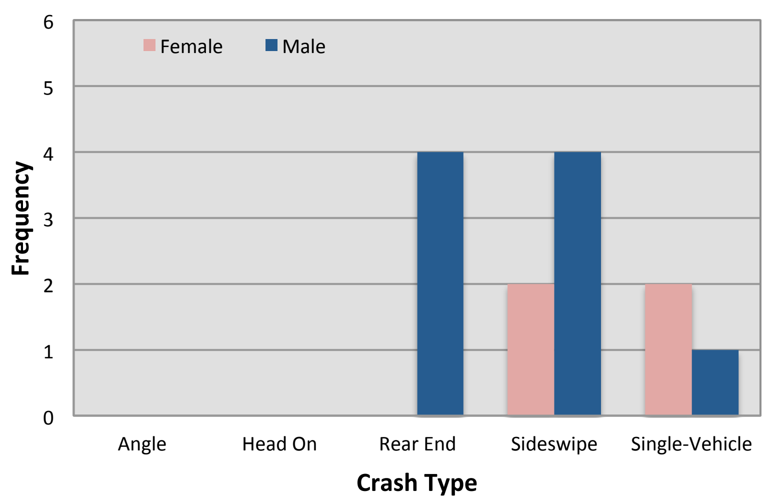


Figure 83: Gender and Crash Type (I75-I285 Control Ramp - After)

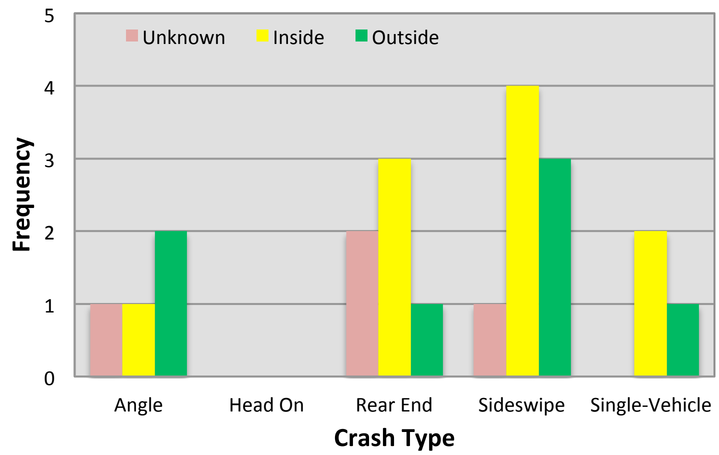


Figure 84: County of Residence and Crash Type (I75-I285 Control Ramp - Before)

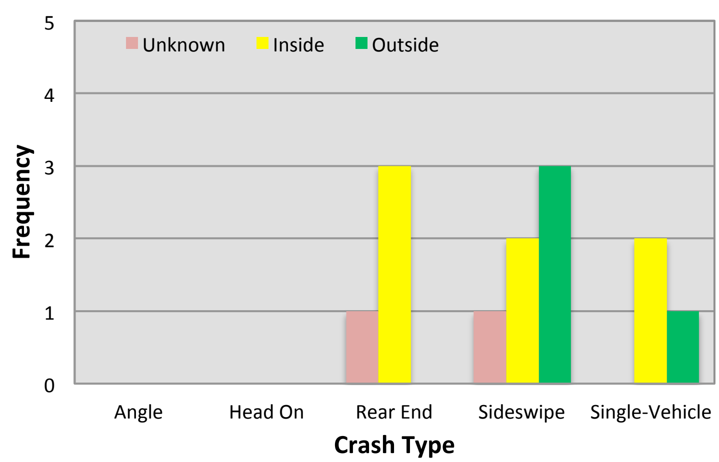


Figure 85: County of Residence and Crash Type (I75-I285 Control Ramp - After)

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